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초 록 집

대한금속·재료학회
THE KOREAN INSTITUTE OF METALS AND MATERIALS

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분과위원장 인사말

세계 각국은 탄소중립 정책 기조 하에 기후변화 대응과 우주산업 개척 등 치열한 기술패권 경쟁에 돌입하였고, 이에 우리나라는 미래성장과 경제안보에 기여할 12대 국가전략기술을 선정하여, 새로운 성장동력을 준비하고 있는 상황입니다. 이중 첨단 모빌리티, 우주항공·해양, 수소, 차세대 원자력 분야 등은 전방위로 핵심 소재에 대한 차별화된 성능 확보에 초격차기술 우위가 크게 좌우된다는 사실에서 구조재료의 중요성이 그 어느 때보다 중요하다고 판단합니다.

이러한 전세계적인 시대적, 산업적 요구에 선제적으로 부응하기 위해서, 대한금속·재료학회 재료강도분과에서는 우리나라 구조재료 분야의 원천기술 개발과 관련한 최신 정보 교류의 장으로 '첨단구조재료 심포지엄'을 매년 개최하고 있습니다. 최근, 급부상하는 우주·항공·방산·원자력이라는 키워드에서도 중요한 기술적 가치를 차지하는 첨단구조재료의 현수준, 기술적 이슈 그리고 앞으로 역할 등에 대해서도 충분한 토론의 장으로서 그 역할을 제공할 것입니다.

올해 심포지엄은 우리 분과 위원장을 역임하신 박경태 교수님의 정년퇴임을 기념하는 자리도 마련되며, 구조재료 분야에서 활발한 연구활동을 이어오신 회원님들께서 74편에 달하는 수준 높은 최신 연구결과를 발표해 주실 예정으로 뜻깊은 시간이 될 것으로 생각합니다.

첨단구조재료 심포지엄을 위해 매년 변함없이 후원해 주시는 여러 후원사와 금번에 신규로 지원해주신 기관들께 진심으로 깊은 감사의 말씀을 올리며, 대한금속·재료학회 회원 여러분들의 큰 성취와 건승을 기원합니다. 앞으로도 재료강도분과는 우리나라 소재산업의 무궁한 발전을 뒷받침하고 국제적 경쟁 우위를 다질 수 있도록 최선을 다하겠습니다.

2024년 08월

(사) 대한금속·재료학회 재료강도분과위원장

홍 현 욱

목 차

제 38 회 첨단구조재료 심포지엄
8월 29일 [목]
제 1 발표회장

- Session 1
- Session 2

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고망간강 레이저 용접부의 망간 기화 모델링 및 인장 특성 거동

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Mn vaporization modeling and tensile properties of high-Mn steel laser welds

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ABSTRACT

The demand for hydrogen energy and the exploration of shale gases in polar and deep-sea regions are increasing. To meet the growing industrial demand in these areas, cryogenic materials must be used, and the fields where such materials are needed is increasing. Commonly used cryogenic materials include 9% Ni and austenitic stainless steel. Recently, high-Mn steel has attracted many interests owing to their excellent mechanical properties at cryogenic temperatures while reducing costs. Weldability is essential in the industrial applications of high-Mn cryogenic steels. Laser welding is expected to be applied to small C-type LNG tanks and pipes, and the alloying element vaporization has received special attention. A keyhole forms during laser welding and vaporizes volatile alloying elements such as Mn and Mg. In this study, we investigated Mn vaporization and tensile properties in relation to keyhole behavior during laser welding.

Fully penetrated and partially penetrated keyhole specimens were produced using a fiber laser in a bead on plate type, by adjusting the defocusing distance. The molten pool temperature and flow behavior were analyzed using CFD simulations, and the keyhole wall temperature was extracted for Mn vaporization modeling calculations. Tensile tests were performed at room temperature and at -163°C.

Mn vaporization occurred more actively in the L-2 (partial penetration keyhole) specimen, where the keyhole wall temperature distribution was the highest. At room temperature, all specimens had a YS above 400 MPa. At −163 °C, both YS and TS increased. In the case of L-2, where significant Mn vaporization occurred, YS slightly increased, while the elongation slightly decreased at both room temperature and cryogenic temperatures. These results were analyzed with regard to the microstructural factors influencing plastic deformation behavior as a result of Mn vaporization.

Keywords: Mn vaporization; high-Mn steel; modeling; laser welding

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316L 스테인리스 강의 용접부에서 용접인자에 따른 수소취화 거동

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Effect of welding parameter on hydrogen embrittlement in weld joint of 316L stainless steel

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ABSTRACT

Stainless steel(SS) 316L ins one of the materials that has recently attracted attention as a material for liquid hydrogen tanks, and verification research on this is being actively conducted. However, most of the studies are limited to the base metal and very few studies on the weld joint have been reported. The weld joint also necessarily requires evaluation because it shows poor mechanical properties compared to the base metal. Therefore, in this study, the hydrogen embrittlement sensitivity of the STS316L weld joint was evaluated according to the temperature.

The materials used in this study were manufactured by gas tungsten arc welding(GTAW) and laser beam welding(LBW) on SS 316L. After electro-chemically charging the specimen with hydrogen, the slow strain rate test was evaluated at room temperature(25℃), -100℃, and -196℃, and the deformation behavior according to the temperature and hydrogen charging was compared.

LB weld joint showed superior cryogenic properties compared to GTA weld joint, accompanied by high hydrogen embrittlement sensitivity. In particular, a marked

difference was observed at room temperature, and both weld joints showed very high hydrogen embrittlement at -100℃. The generation of cracks was influenced by the change of the deformation mechanism according to delta ferrite and stacking fault energy. The following results were investigated through the microstructural factors along with hydrogen diffusion and trap behavior.

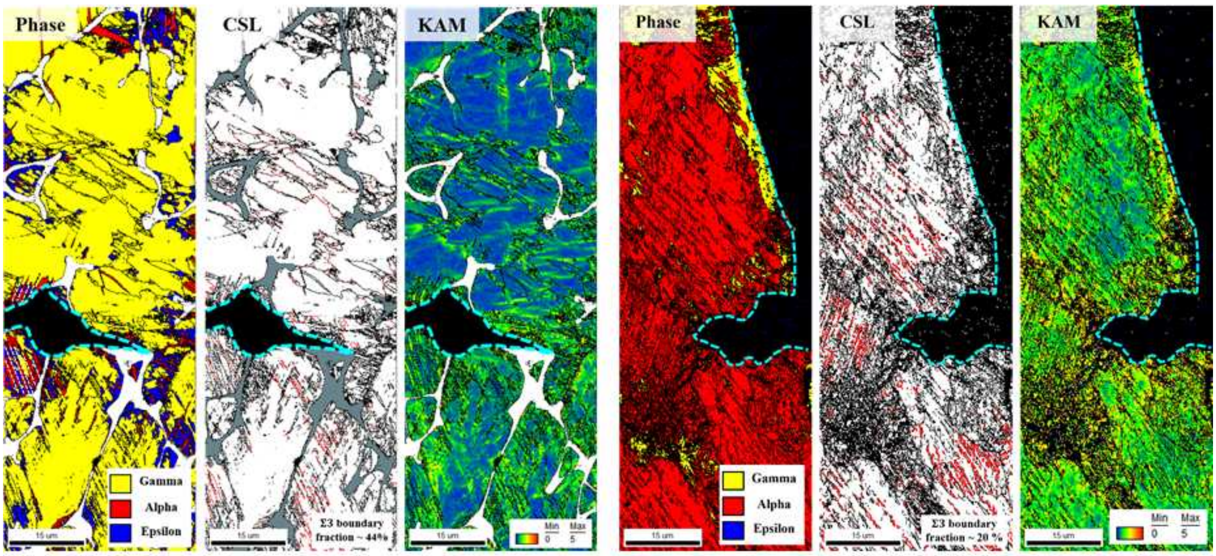

Fig 1. EBSD maps of **a,d** phase, **b,e** CSL and **c,f** KAM after SSRT at -100 degree: **a,b,c** GTA weld joint, **d,e,f** LB weld joint

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STS 308L/316L 전용착금속의 δ-ferrite와 stain-induced martensite가 수소취성에 미치는 영향

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Effect of δ-ferrite and strain-induced martensite on hydrogen embrittlementt of STS 308L and 316L all-weld metals

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ABSTRACT

Stainless steels (STS) 304L and 316L are increasingly popular for liquid hydrogen storage tanks due to their high hydrogen solubility and low diffusivity. However, most research has focused on the base metal, with limited studies on welds. Weld metals must be evaluated because their properties are often inferior to those of the base metal due to complex heat cycles and rapid cooling. This study examines the sensitivity of STS 308L and STS 316L all-weld metals to hydrogen embrittlement at various temperatures.

Materials used in this investigation included Flux-cored arc weld (FCAW) STSs 308L and 316L. Slow strain rate tests (SSRT) were conducted at 25 °C, -100 °C, and - 196 °C to assess the deformation behavior of the specimens in relation to temperature and hydrogen after electrochemically hydrogen charging.

The sensitivity to hydrogen embrittlement of STS 308L and STS 316L all-weld metals was found to be highest at - 100 °C and lowest at - 196 °C. Crack initiation and propagation were influenced by interdendritic δ-ferrite and strain-induced martensite. These results were analyzed considering microstructural factors, along with hydrogen diffusion and trapping behavior.

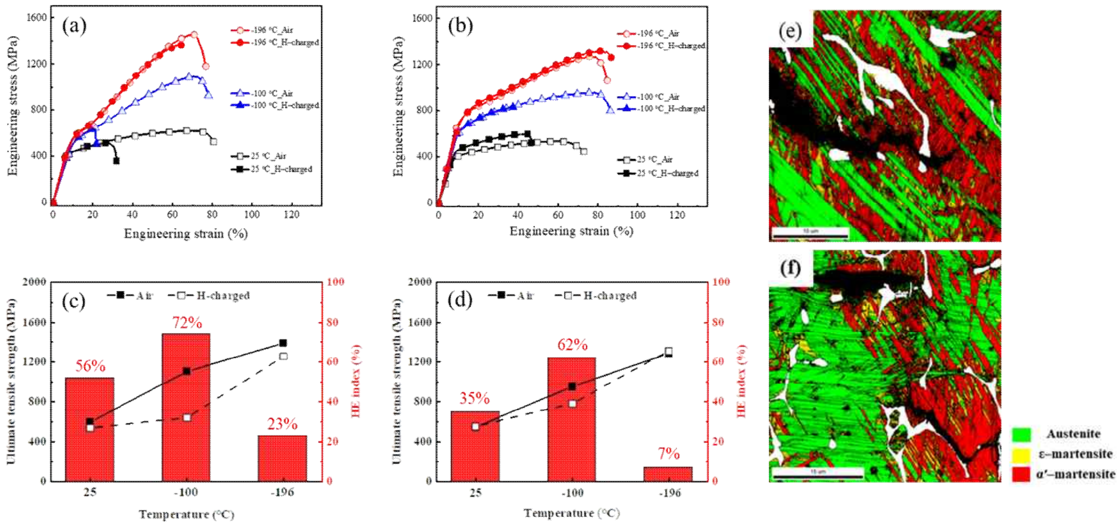

Fig. 1. Engineering stress - strain curves of (a) STS 308L and (b) STS 316L all-weld metals; UTS and HE index of (c) STS 308L and (d) STS 316L all-weld metals; phase map of (e) STS 308L and (f) STS 316L highlighting δ-ferrite in white of H-charged specimen tested at -100 ℃

Keywords: hydrogen embrittlement; stainless steel; δ-ferrite; strain-induced martensite

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고내식 경량고강도 합금의 열처리 온도에 따른 상변태 거동

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Phase Transformation on the Heat Treatment in Corrosion Resistant FeMnAlC Lightweight Steel

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ABSTRACT

Phase transformation of lightweight steel (Fe-29.1Mn-12.5Al-1.35C-4.95Cr) has been investigated in the present study. This steel was designed based on a Cr-added Fe-Mn-Al-C alloy system, which has been considered as a new class of lightweight stainless steel performing not only high specific strength and ductility but also comparable corrosion resistance to the conventional stainless steels [1]. The steel consists of austenite, ferrite, and κ-carbide, which leads to precipitation strengthening even through solution treatment (1050 °C/2 h/WQ) alone. Generally, the addition of Cr inhibits the formation of κ-carbide. However, in this study, the inhibitory effect was negligible due to the high content of Al and C, which act as driving forces for the precipitation of κ-carbide. According to the phase diagram calculated using Thermo-Clac software (TCFE12 database), κ-carbide starts to precipitate below 1000 °C, as shown in Figs. 1(a) and 1(b). This implies that κ-carbide readily precipitates during cooling despite the rapid cooling rate. In the temperature range of 550-850 °C,

FeAl-type B2 phase, κ-carbide, and carbides ($M_{23}C_6$ and M_7C_3) are expected. However, β-Mn, a harmful phase, was undesirably precipitated at grain boundaries at the initial stage of heat treatment and grew towards the interior of the austenite grains. For the formation of β-Mn, the C content has to be below 5 wt.%, as shown in Fig. 1(b). It is expected that the formation of intergranular carbides ($M_{23}C_6$ or M_7C_3) consumed C atoms near grain boundaries, resulting in C-depleted areas. These C-depleted areas acted as driving forces for the formation of β-Mn at grain boundaries. Meanwhile, the formation and growth of β-Mn occurred more rapidly at higher temperatures, exhibiting different morphological characteristics depending on the temperature. In this study, we aimed to discuss the undesirable preciptiation of β-Mn and the resulting phase transformation behavior.

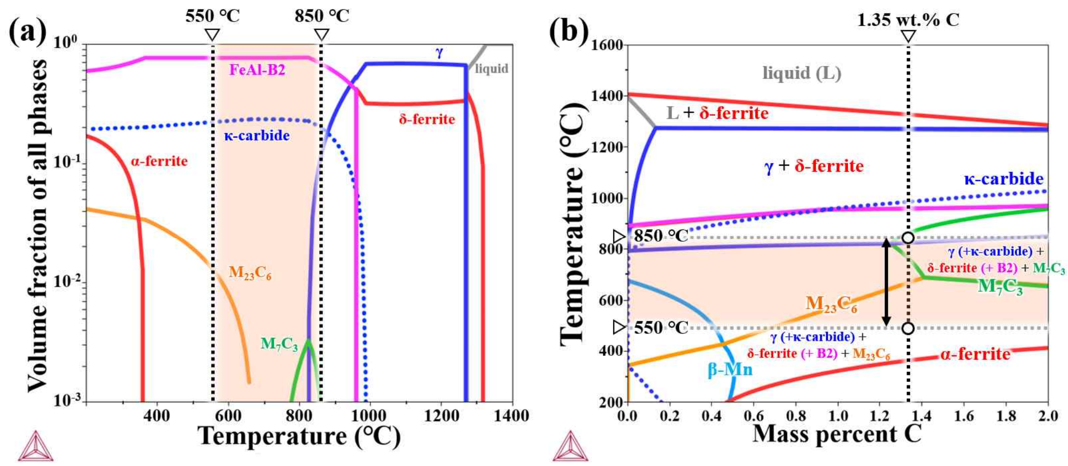

Fig. 1. Phase diagram calulcated using Thermo-Calc software (TCFE12 ver.): (a) phase fraction vs temperature, and (b) temperature vs C wt.% diagrams.

References

[1] J. Moon, H. Ha, K. Kim, S. Park, T. Lee, S. Kim, J. Hang, H. Jo, H. Hong, B. Lee, Y. Lee, C. Lee, D. Suh, H. Han, D. Raabe, C. Lee, Sci. Reports, (2020) 10:12140.

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자동차용 초고강도강 플래시버트 접합부 미세조직 및 인장특성

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Microstructure evolution and tensile properties in flash-butt welded joints of automotive ultra-high strength steel

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ABSTRACT

This study aims to investigate the effects of post-heating on microstructutre evolution and tensile properties in flash-butt welded joints of ultra-high strength 23MnB5 steel, which has a tensile strength of 1500MPa upon quenching. To this end, post-heating was applied to joints just after flash-butt welding in order to decrease the cooling rate to room temperature and the cooling rate then decreased with increasing post-heating current.

Microstructure evolution and precipitation behavior in welds were characterized by scanning electron microscopy (SEM), electron backscattered diffraction (EBSD), and transmission electron microscopy (TEM) analyses. Weld microstructures consisted of bainite, martensite, and iron-carbides such as cementite and η-carbide. Prior austenite grain size and lath width of bainite and martensite increased with increasing post-heating current in both bond-line and coarse-grained heat-affected zone. In addition, the precipitation of fine η-carbides and the coarsening of cementite occurred with increasing post-heating current. Mechanical properties in welds were evaluated by Vickers hardness and micro-tensile tests. Finally, the mechanisms for changing tensile properties in welds with varying post-heating condition was analyzed in terms of microstructure evolution.

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잔류원소가 포함된 고강도강에서 미량합금원소가 구멍확장성(HER)에 미치는 영향

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Influence of Micro-alloying elements on Hole Expansion Ratio (HER) in High-strength Steel Containing Tramp Elements

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ABSTRACT

Carbon emissions are one of the most critical challenges faced by the steel industry. One effective method to reduce carbon emissions is to increase the use of steel scrap, which inevitably raises the content of tramp elements. Therefore, it is crucial to investigate how tramp elements affect the mechanical properties of steels to manage their accumulation. Tramp elements tend to segregate at surfaces or boundaries, adversely affecting mechanical properties. The impact of tramp elements could be particularly significant for properties like the hole expansion ratio (HER), which are governed by crack initiation and propagation behaviors could be stimulated by tramp element segregation. Among the various microstructures of steels, those particularly vulnerable to tramp elements could be predicted to be cases where the tramp elements segregate at the crack initiation site. In this context, micro-alloyed steel containing significant amounts of Ti could be a primary candidate for investigating tramp element contamination. High Ti content results in a considerable amount of coarse TiN precipitates, which act as crack initiation sites. Moreover, the interface between TiN precipitates and the matrix could be a segregation site for tramp elements, stimulating crack initiation. Thus, elucidating the impact of tramp

elements on HER in micro-alloyed steel and developing strategies to mitigate HER degradation caused by tramp elements is worth investigating.

To overcome HER degradation in micro-alloyed steel due to tramp element contamination, it is necessary to control the precipitation behavior of coarse precipitates. Selecting appropriate types of micro-alloying elements can be an effective approach to controlling the precipitation behavior of these coarse precipitates. Therefore, the present study aimed to comprehensively investigate the effects of micro-alloying elements on HER in steels containing tramp elements. To isolate the effect of different tensile properties on HER, steel compositions were carefully designed to have similar tensile properties by adjusting the amounts of Nb and Ti. Then, tramp elements were gradually added to each specimen to elucidate their effect on HER. To address the effect of hole-processing factors on HER, the holes were machined by two distinct methods: punching and wire-EDM. Finally, the interaction between precipitates and tramp elements was analyzed using 3D-APT and first-principle calculations. High Ti content in micro-alloyed steel promoted the formation of coarse TiN-based precipitates, increasing damage during the hole punching process and negatively impacting HER. Additionally, segregation of tramp elements at the interface of TiN-based precipitates and matrix exacerbated punching damage. In conclusion, Ti-rich specimens experienced greater punching damage than Nb-rich specimens in the presence of tramp elements due to the higher amount of TiN-based precipitates, whose interface cohesion energy weakened due to the segregation of tramp elements.

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10Cr 페라이트/마르텐사이트계 내열강에서 초기조직이 오스테나이트 역변태 거동에 미치는 영향

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Influence of initial microstructure on the reverse transformation in 10Cr ferritic/martensitic heat-resistant steel

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Pohang University of Science and Technology[1)], Korea Institute of Materials Science[2)], Doosan Enerbility[3)]

ABSTRACT

증기터빈용 로터에 사용되는 10Cr 내열강은 열처리 공정 중 오스테나이트화 처리를 거치게 되며, 내열강의 오스테나이트화 거동에 대한 이해는 후속 열처리에 의해 원하는 기계적 특성을 나타내는 미세조직을 확보하는데 매우 중요하다. 오스테나이트 역변태 거동은 합금성분, 승온 속도, 오스테나이트화 온도에 크게 영향을 받는 것으로 알려져 있으나, 내열강에서의 초기조직이 오스테나이트 역변태 거동에 미치는 영향에 대한 연구는 많지 않다. 본 연구에서는 10Cr 내열강에 대해 초기조직이 오스테나이트 역변태 거동에 미치는 영향을 정량적으로 분석하였다.

마르텐사이트로 이루어진 초기 미세조직(sample A)과 페라이트와 Cr 탄화물이 존재하는 평형에 가까운 초기 미세조직(sample B)에 대하여 동일한 승온 속도로 오스테나이트화 온도로 가열 후 유지시간에 따른 역변태 거동의 변화를 관찰하였다. 페라이트와 Cr 탄화물로 이루어진 초기 미세조직의 경우에는 1050°C로의 승온 후, 4시간 동안 유지하여도 소량의 페라이트가 여전히 잔류하여 완전한 역변태가 이루어지지 않았다. 이러한 결과는 Cr 탄화물의 분해에 따른 Cr 확산에 의해 페라이트가 상당한 시간 동안 안정화될 수 있기 때문인 것으로 보여지며 이에 대한 정량적인 해석을 제시하고자 한다.

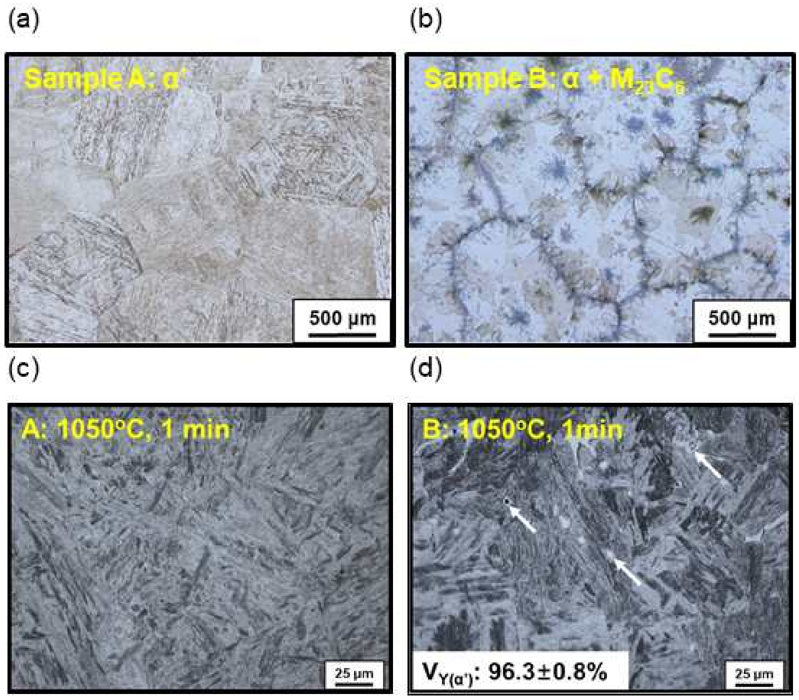

Fig 1. (a) sample A의 초기 미세조직, (b) sample B의 초기 미세조직, 1050 °C에서 1분간 열처리를 진행한 후 (c) sample A의 미세조직과 (d) sample B의 미세조직

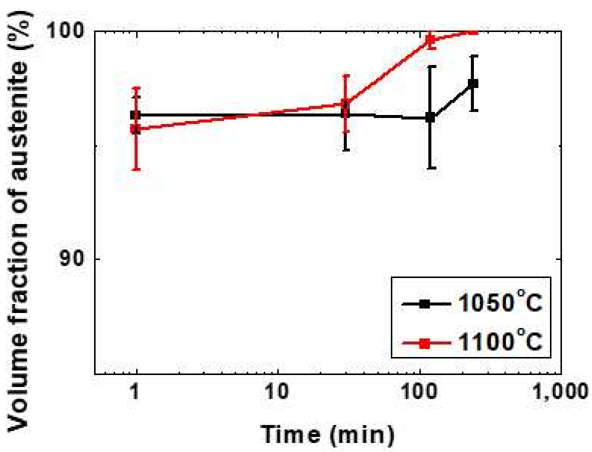

Fig 2. 1050 °C와 1100 °C에서 열처리 시간에 따른 sample B의 오스테나이트 상분율 변화

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Deformation-induced martensitic transformation vs deformation twinning

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Deformation-induced martensitic transformation vs deformation twinning

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ABSTRACT

A challenge to tailor the properties of steels for structural applications requires a profound understanding of deformation mechanism in materials design and property enhancement. In austenitic steels with face-centered cubic (fcc) structure, deformation-induced martensitic transformation (DIMT) and deformation twinning (DT) have received increasing attention owing to their favorable contributions to strength-elongation balance. Although several models for DIMT and DT have been proposed and attempts have been made of providing experimental evidences to support the models, discrepancies remain about the essential parameters dictating nucleation of martensite and twin and about the dislocation activities governing plasticity. To resolve the uncertainties underlying DIMT and DT, we propose dislocation-based models to understand DIMT and DT based on the systematic two-beam analyses on dislocations. The formation mechanism of DT can be explained by the three-layer twin model. For DIMT, we propose a dislocation based model for sequential fcc-hcp-bcc transformation. Apart from previous models for direct fcc-to-bcc MT, two-step transformation composed of fcc-to-hcp followed by hcp-to-bcc was a main transformation path. For the first stage of fcc-to-hcp MT, Frank partial dislocation played a decisive role in the formation of hcp martensite.

And, two invariant-plane strains are required to complete the hcp-to-bcc MT. By incorporating our dislocation model into the concept of stacking fault energy, we suggest a synthesized concept of deformation scenario that can provide fundamental and predictive insight into plasticity and transformability of fcc material.

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낮은 열전도도를 갖는 오스테나이트계 Fe-Mn-Ni-Al 합금의 4.2 K 초극저온 인장 거동 특성

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Tensile behavior of austenitic Fe-Mn-Ni-Al alloy with low thermal conductivity at an extremely low temperature of 4.2 K

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Abstract

In accordance with an increase in concerns for the global warming, needs for the use of eco-friendly energy of liquid hydrogen (H) have also increased. To this end, it has become important to procure the reliability of structural materials in the cryogenic temperature range including absolute zero. Therefore, the face-centered cubic (*fcc*) structure-based materials, such as austenitic stainless steel and high entropy alloy, have been considered the best candidates for the cryogenic applications due to their superior mechanical properties with a high reliable elongation. However, when these *fcc* structure-based materials undergo the plastic deformation at extremely low temperatures below ~35 K, they exhibited serrated flow in their tensile curves. The serrated flow at the extremely low temperatures, *i.e.*, the cryogenic serration, is featured by the shear bands appearing on the gauge portion of tensile specimen during tensile deformation. To theoretically understand the cryogenic serrations, several researchers have proposed two representative models: 1) Thermomechanical instability model based on the extremely low thermal conductivity (κ) and heat capacity (C_p) and 2) mechanical instability model based on the dislocation avalanche.

It should be noted that in the extremely low temperature range below ~35 K, materials show the extremely low thermal properties (κ and C_p). Therefore, the generation and dissipation behavior of adiabatic heats during tensile deformation at the extremely low temperatures should be considered. Since the occurrence of shear

bands faciliates the generation of adiabatic heats due to the concentration of tensile strain into the local shear band region, it becomes more important to consider the extremely low thermal properties. Therefore, in this study, we aim to investigate the effect of the extremely low thermal properties on the tensile behavior of *fcc* structure-based material at 4.2 K.

For this purpose, *fcc*-austenitic Fe-16Ni-15Mn-1.5Al (wt%) alloy possessing low thermal properties was adopted. Using this alloy specimen, a tensile test was performed at 4.2 K with an initial strain rate of 1×10^{-3} /s. The tensile temperature was preserved using liquid helium. In addition, microstructural observations revealed that an *fcc* single phase was conversed even after the tensile testing at 4.2 K.

Fig. 1a shows the tensile flow curve of the present alloy obtained at 4.2 K. The tensile curve showed serrated flow featuring an oscillation shape above and below the general stress level. It is noteworthy that the tensile curve showed little post-uniform elongation after engineering stress attains ultimate value. Furthermore, when investigating the magnitude of stress drop of cryogenic serrations (Fig. 1b), although the magnitude increases as the tensile strain increases, the increase rate of the magnitude in accordance with tensile strain becomes higher than before at a certain tensile strain of ~0.55. These two (little post-uniform elongation and higher increase rate of the magnitude of stress drop) are thought to originate from the extremely low thermal properties.

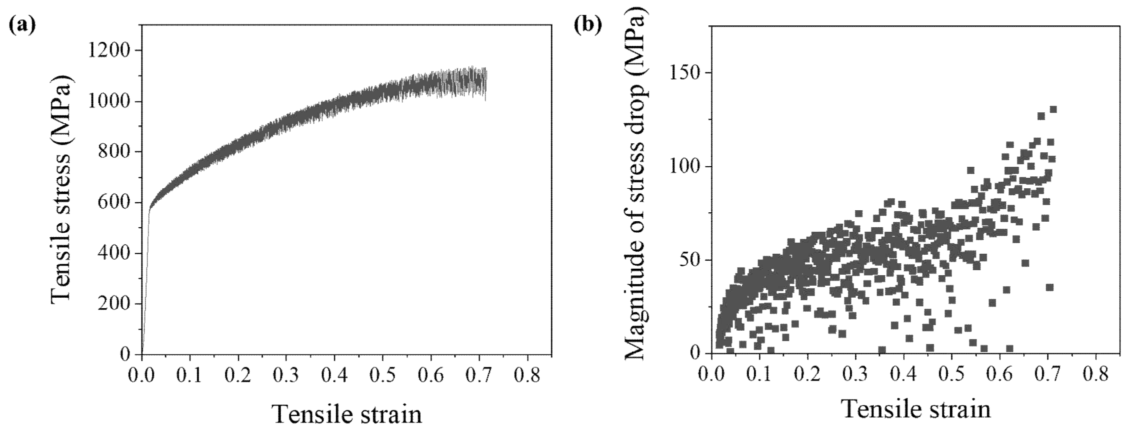

Fig. 1. (a) Engineering tensile stress-strain curve of the present alloy obtained at 4.2 K with an initial strain rate of 1×10^{-3} /s. (b) Variation in the magnitude of stress drop of cryogenic serrations as a function of tensile strain.

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초고강도 및 고연성 기가스틸 용접금속 미세조직 세립화를 통한 피로특성 향상 연구

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Improving the fatigue performance of ultrastrong and ductile GIGASTEEL welds with interwoven nature

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ABSTRACT

Although the need for automobile lightening continues to increase in preparation for the era of electrical vehicles, the application of steel, which has strengths in price and recycling in the automotive industry, is expected to continue along with the developments of various driving energy sources. Recently, when lightening and stiffness reinforcement are required for the electric vehicles or medium and large SUVs, newly-designed parts using GIGASTEEL with a tensile strength of 980MPa or higher are being developed. However, it is difficult to secure sufficient weld strength and fatigue performances when applying welding consumables that have been applied normally and ultra-high strength welding materials that have been commercialized so far. It has also limitations that are not easy to apply due to excessive manufacturing costs in the automotive industry.

The bainite phase transformation can be explained through a displacive mechanism using the Bain distortion model. Since the bainite transformation and acicular ferrite transformation develop competitively depending on the grain size of the parent austenite, the cleanliness of the grain boundaries, and the effective distribution of oxide inclusions, it is necessary to review the development of process technology that

considers optimal alloy design and cooling rates to control these factors.

While research and development have been actively utilizing acicular ferrite transformation as a means to effectively enhance both the strength and toughness of high-strength weld metals, recently, in the case of GIGASTEEL with a tensile strength of 980 MPa or higher, which is increasingly being applied in the automotive industry, the steel thickness is typically less than 2.0 mm. Compared to thicker plates, the cooling rate of the weld zone is relatively slower, and due to the influence of various alloying elements, it exhibits complex microstructural characteristics, including bainite transformation. Particularly, from the perspective of bainite transformation temperature and morphology, it is necessary to comprehensively consider the effects of alloying elements as well as the grain size of austenite and the cooling rate.

In this study, the application of commercial welding consumables by strength grade to GIGASTEEL was reviewed and the properties of the weldments were compared to address all of the above issues. Here, we consider the effects of C, Mn, Si, Cr, Ni, Mo and microalloying elements to implement interlocked nature with denser and finer microstructures of bainite, acicular ferrite (highly-misorientated) and film-like retained austenite that can effectively improve both strength and toughness of GIGASTEEL welds in a more economical way.

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고장분석을 통한 자동차용 고강도강의 미세조직 영향 규명

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Case studies in failure analysis of automotive chassis parts

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ABSTRACT

자동차에 적용되는 환경 및 안전규제는 매년 강화되고 있으며 이에 맞추어 자동차용 철강소재의 고강도화 및 고기능화는 지속적으로 확대되고 있다[1]. 특히, 베터리로 인해 무게가 증가하는 전기자동차에 있어서는 주행 중 샤시 (chassis) 부품에 가해지는 피로하중이 더 증가하게 되므로 기존 보다 내구성이 우수한 고강도 강재가 필요하다. 또한, 이와 같은 자동차의 샤시 부품은 강성 및 주행 안정성, 내부 공간의 확보, 적정한 차고유지 등 본래의 기능에 적합하도록 설계되어야 하며 타 부품과 연동되어야 하므로 형상이 복잡하고 다양한 크기의 홀을 갖는 특징이 있다. 따라서 샤시 부품용 강재는 그림 1에 나타낸 것처럼 부품 성형에 필요한 다양한 물성을 만족해야 한다.

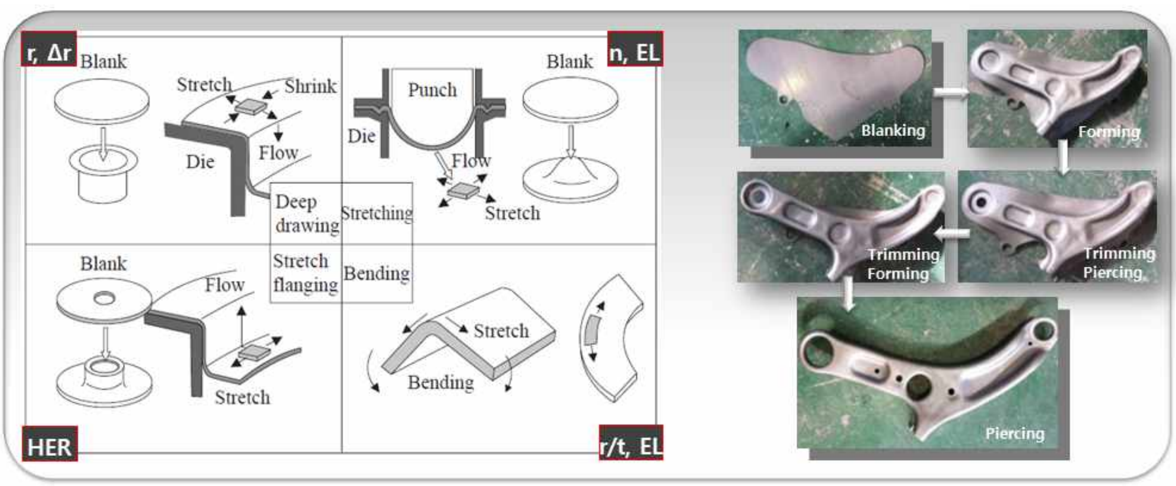

그림 1. 판재성형시 요구되는 모드별 소재의 물성과 대표적인 샤시부품의 성형과정 사례

일반적으로 내구성이 필요한 자동차의 샤시 부품에는 Nb, Ti 등의 미량합금원소를 이용하여 미세한 조직을 얻고 석출강화 효과를 활용하는 고강도 저합금강(HSLA강)이 사용된다. 하지만 대부분 인장강도 기준 440~590MPa급 강재로 비교적 낮은 수준에 해당하며 그림 1에서 나타낸 홀 확장 성형시 요구되는 HER(Hole Expansion Ratio)은 낮은 값을 보여 버링부 및 플랜지부 성형시 불리한 문제가 있다. 그림 2에는 현재 Nb, Ti 첨가 석출강화강을 사용중인 실부품에서 발생한 여러 가지 문제점에 대해 그 원인규명 및 해결 방안 도출을 위한 고장분석 (Failure Analysis) 사례를 나타내었다. 실제 부품에서 발생한 불량(고장)의 형태는 크게 버링부위 및 플랜지부위 크랙과 같이 성형 중에 발생한 크랙과 성형이 완료된 부품의 성능 평가단계에서 발생한 불량 그리고 사용 중 발생한 파손의 경우로 구분할 수 있었다. 각각의 불량 원인을 분석한 결과, 성형공정이나 부적합한 부품 설계가 원인인 경우도 있었으나 대부분의 경우는 잘못된 소재의 선정과 관련이 있음을 확인하였다. 이는 앞서 언급한 것처럼 Nb 및 Ti 첨가 석출강화강의 낮은 HER값이 원인이며 이는 기존의 제품과 동등수준의 항복강도 및 연신율을 유지하면서 동시에 HER을 향상시키는 기술 개발이 필요함을 의미한다. 특히, 불량부위에서 형성된 크랙의 위치, 전파 형태, 결정립계 부근의 조대한 탄화물 형성 여부 및 미세조직의 불균일성 등을 확인함으로서 크랙의 발생 및 전파에 대한 저항성을 향상시키기 위해서는 베이니틱 페라이트 조직을 기지조직으로 하고 강재가 필요로 하는 강도 수준에 적합하도록 제2상으로 베이나이트 및 마르텐사이트 등의 경질상이 형성되도록 제조하는 것이 필요함을 확인하였다.

대상 부품		적용소재			불량 형태	발생시기 /심각도	원인/발생기구		
부품명	형상	규격	두께	특징			소재선정	성형공정	기타
Seat Recliner		S500MC	2.5t	Nb-Ti Microalloyed Steel	버링부위 크랙	부품성형 중 /Lv. 2~6 (경미한 생산중단)	○	○	
Subframe		S500MC S700MC	2.0t		플렌지부 크랙		○		
Seat Belt Pretensioner		SPFH590	3.2t 3.4t	Nb Microalloyed Steel	플랜지부 굽힘부 크랙		○		
Spring Seat		SPFH590	4.0t		버링부위 크랙		○	○	
Lower Control Arm		S550MC	4.0t	Nb-Ti Microalloyed Steel	버링부위 플랜지부		○		
Airbag Inflator		S420MC	2.5t	Nb Microalloyed Steel	저온 내충격 파괴	성능평가 /Lv. 7~9	○		
Torsion beam		S550MC	4.0t	Nb-Ti Microalloyed Steel	차량운행중 파손	사용중 /Lv. 8~10 (안전문제 사용불가)			○
Spring Seat		SPFH590	4.0t	Nb Microalloyed Steel			○	○	
Lower Control Arm		S550MC	4.0t	Nb-Ti Microalloyed Steel			○		○

그림 2. 실제 부품에 대한 고장분석 (Failure Analysis) 사례

[1] Emissions Regulations in the Coming Mobility Era, World Steel Association, https://www.worldautosteel.org/why-steel/steel-your-environment/

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통합전산재료공학과 인공지능을 활용한 고성능 내진내화강 설계

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Integrated Computational Materials Engineering for Fire Resistant Steels

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초록

내화강(Fire-Resistant Steel)은 화재 시 건축 구조물을 유지할 수 있어야 하므로 고성능 내진내화강을 설계하기 위해서는 고온(600도)에서의 강도가 매우 중요하다. 본 연구에서는 CALPHAD기반 고속대량스크리닝 기법을 활용하여 총 30,000개 이상의 조성에 대한 기계적 물성을 예측하였다. 30,000개 조성의 데이터베이스 중에 약 4,600개 조성의 경우 내화강 설계에서 요구하는 고온(600도) 234MPa이상의 항복강도 조건을 만족하였다. 설립된 빅 데이터베이스를 바탕으로 인공지능을 활용하여 합금 내 각 원소와 기계적 물성 간의 상관관계를 파악하였고, 합금 내 원소 중 강화상(탄화물) 생성을 초래하는 원소(예. Nb, Cr, V)가 효과적임을 예측하였다. 설립된 30,000개 데이터베이스 중 가장 최적의 조성을 택하여 고온인장시험을 통해 모델링의 정확성을 검증하였다. 실험 결과 고온(600도)에서 520MPa이상의 항복강도를 보였으며 기존의 상업용 내화강(S355)에 비해 우수함을 보였다. 본 연구에서 제시한 통합전산재료공학 기반 합금 설계 방식이 앞으로 다양한 합금 설계에 표준 방식으로 제안될 것이라 생각한다.

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수소가 첨단 고강도강(AHSS)의 미세구조 및 기계적 성질에 미치는영향

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Effect of hydrogen om the microstructure and mechanical properties of advanced high strength steels (AHSS)

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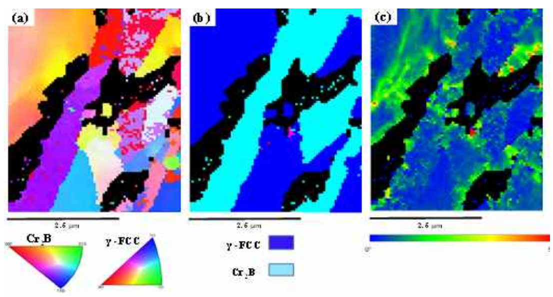
Abstract

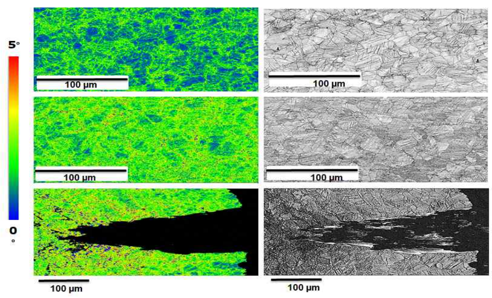
Advanced high strength steels (AHSS) are widely used in various industries, including the automotive industry and car bodies, due to their strength and high ductility. From the production process of advanced high strength steels to their use in hydrogen energy applications, they are exposed to hydrogen embrittlement. In this research, four advanced high strength steels, Fe65.95C0.45Cr15.5Ni14.1Si3(AHSS_C0.45),Fe65.95C0.45Cr15.5Ni14.1B2Si3 (AHSS_C0.45B2) Fe65.95C0.021Cr15.5Ni14.1B2Si3 (AHSS_ C0.021B2), and metastable 304 austenitic stainless steel, we reused to investigate their mechanical and microstructural behavior in the presence of hydrogen. To investigate the hydrogen embrittlement and deformation mechanisms of steels in the presence of the hydrogen, in situ electrochemical tensile test was performed. The results showed that after electrochemical charging of hydrogen for all steels, the yield strength, tensile strength and elongation of the steels decreased compared to the uncharged samples. The

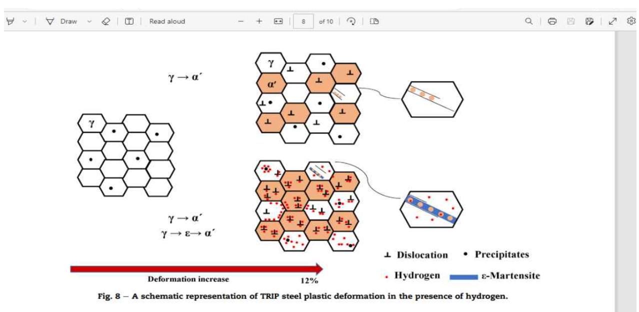
greatest reduction in tensile strength and elongation was for metastable 304 stainless steel. AHSS_C0.45 steel had the lowest brittleness index of 14, while metastable 304 stainless steel implied the highest brittleness index of 54 due to the TRIP effect during deformation. The results of backscattered electron diffraction(EBSD) of interrupted tensile samples in the presence and absence of hydrogen showed that the dislocation density increased after hydrogen charging and led to more stress concentration in the matrix. The deformation mechanism for AHSS_C0.021B2 and metastable austenitic 304 austenitic stainless steel was phase transformation of austenite to martensite. By reducing the stacking fault energy, hydrogen caused the formation of a larger amount of martensite α′ phase and the growth of cracks at the interface of austenite and martensite, which is a reason for the significant loss of mechanical properties in these steels compared to the other two steels in the presence of hydrogen. In compatibility of plastic strain between austenite and boride phases and non-rotation of austenite grains of boron-containing steel AHSS_C0.45B2 caused crack initiation and grow that the interface between austenite and boride phase and had a significant drop in mechanical properties compared to boron-free steel(AHSS_C0.45) in the presence of hydrogen.

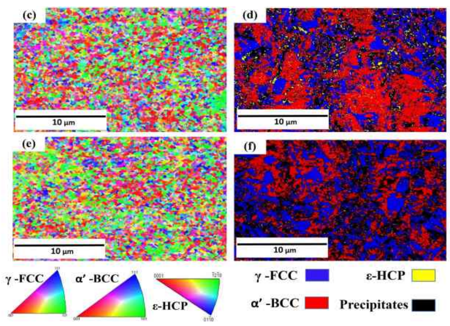
Keywords: Hydrogen embrittlement, advanced high strength steel, deformation mechanisms, stainless steel, dislocation.

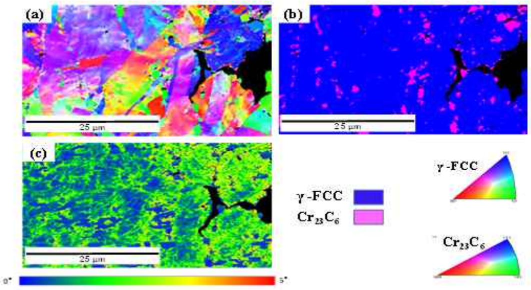
(metastable 304 austenitic stainless steel)
(AHSS_ C0.021B2) (AHSS_C0.45)(AHSS_ C0.45B2)



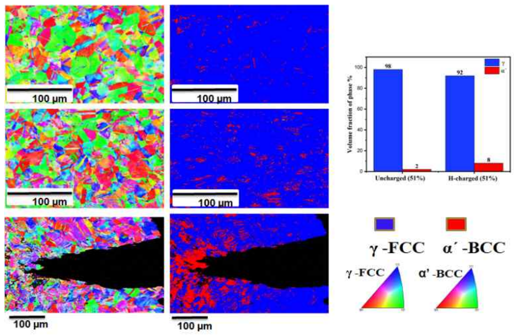








(a)
(b)
(c)
25 μm
25 μm
25 μm
γ-FCC
Cr23C6
0°
5°



100 μm
100 μm
100 μm
100 μm
100 μm
100 μm
98
92
2
8
Uncharged (51%)
H-charged (51%)
γ-FCC
α′-BCC

제 38 회 첨단구조재료 심포지엄

8월 29일 [목]

제 2 발표회장

- Session 1
- Session 2

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임계 간 열처리를 거친 9% 니켈강의 미세조직 변화에 따른 극저온충격인성 향상

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Microstructural changes and enhancement of cryogenic impact toughness in 9% nickel steel thorugh intercritical annealing heat treatment

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ABSTRACT

Due to environmental concerns, the global shift away from fossil fuels has increased the demand for alternative energies like Liquefied Natural Gas (LNG), which require storage at extremely low temperatures. This necessitates materials that maintain excellent impact toughness in cryogenic environments. Nickel steel, particularly 9% nickel steel, is favored for its ability to stabilize the austenite phase, providing superior impact toughness. However, nickel's low productivity and economic efficiency have led to research into substituting it with other elements like Mn. Unfortunately, these substitutions can weaken grain boundaries, increasing brittleness. This study aims to enhance the cryogenic impact toughness of 9% nickel steel through heat treatment, specifically intercritical annealing, rather than reducing nickel content or using alternative alloying elements. Specimens were subjected to various heat treatment stages, and Charpy V notch tests were performed at -196°C and -253°C to assess cryogenic impact toughness. Microstructural and fracture surface

analyses, along with nanoindentation tests, were conducted to understand the effects of different microstructures on impact toughness. The goal is to design a material with improved impact toughness by analyzing the relationship between heat treatment-induced microstructural changes and mechanical properties.

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최종소둔에 따른 Fe-Si계 합금의 미세구조와 자기적 특성의 상관관계 분석

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Correlation of magnetic properties with microstructures in Fe-Si alloy under final annealing

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ABSTRACT

Fe-Si계 합금은 높은 규소 함유량과 자화가 용이한 미세구조로 이루어져 있어 낮은 보자력과 높은 전기밀도를 가지는 연자성 재료로 전기차 구동모터나 변압기 등에 적용되고 있다. 이러한 Fe-Si계 합금이 구동모터의 고성능화로 고주파 환경에서의 적용이 요구되어지고 있다. 하지만 고주파 환경에서 자기적 특성이 악화되어 에너지 효율이 급감할 수 있는 이슈가 있다. 이러한 외부 환경에 따라 자기적 특성이 악화되는 이유로는 Fe-Si계 합금의 생산 공정 중 발생할 수 있는 산화막, 개재물과 미세구조가 합금 내부 자구의 이동 및 회전을 방해하여 연자성 특성을 악화시킬 수 있기 때문이다. 이러한 자기적 특성을 평가하는 지표 중 하나인 철손은 Fe-Si계 합금이 모터로 구동될 때 발생하는 열손실을 의미하며, 고성능 Fe-Si계 합금을 위해선 철손의 최소화가 필수적이다. Fe-Si계 합금의 철손의 최소화를 위해선 미세구조에 따른 철손 평가 및 상관관계에 관한 연구가 매우 중요하다. 따라서 본 연구에서는 공정에 따른 Fe-Si계 합금의 미세구조를 관찰하고, 철손을 평가하여 미세구조와 철손과의 상관관계를 분석하여 Fe-Si계 합금의 자기적 특성에 영향을 미치는 주요 미세구조 인자를 조사하고자 한다.

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주름 구조 실리카 봉지 재료의 연신 특성 향상

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Improvement of Tensile Properties of Silica Encapsulation Material with Wrinkled Structure

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ABSTRACT

Organic-based devices have limited operational lifetime due to their vulnerability to moisture, oxygen, and external contaminants. Therefore, encapsulation materials are essential to protect these devices. To ensure the operational lifetime of organic-based devices, an encapsulation material with a water vapor transmission rate (WVTR) below 10^-4 g/m^2/day is required. Achieving low WVTR necessitates the use of high-density materials. However, there is a trade-off relation between density and stretchability, as high-density materials typically exhibit low stretchability. To address this issue, we focus on enhancing stretchability through structural approach rather than material modifications. We aim to employ PE-ALD silica to achieve a high-density material and enhance its stretchability by forming a wrinkled structure. The goal is to guarantee the long-term stability of organic-based devices by using an encapsulation material with both high stretchability and low WVTR.

We optimized plasma enhanced atomic layer depostion(PE-ALD) process for silica films at various temperatures to fabricate high-density silica films. Following optimization, we conducted tensile tests to measure the mechanical properties of the silica. Then we fabricated wrinkled structures by applying pre-strain to improve stretchability using these silica films. The pre-strain values were calculated based on the shear modulus ratio of the materials. Based on mathematical modeling, we calculated the amplitude, wavelength, and critical strain of the wrinkled structures.

And we measured the barrier properties through electrical Mg test to evaluate the feasibility of the encapsulation materials. We plan to apply this wrinkled encapsulation material to stretchable organic-based devices to ensure their operational lifetime.

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베이나이트 불완전변태 모델 적용을 통한 다상조직 Q&P강 상분율 예측

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Prediction of phase fractions in multi-phase Q&P steels using bainite transformation stasis model

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ABSTRACT

Phase fraction in quenching-and-partitioning (Q&P) steels consisting of martensite and retained austenite can be predicted using the method proposed by J. G. Speer et al.[1]. The method assumes that carbon atoms partition into austenite completely with no additional phase transformation during partitioning. However, M. J. Santofimia et al.[2] and F. HajyAkbary et al.[3] have shown that phase transformation can occur during partitioning. In such cases, the conventional approach, which assumes no phase transformation during partitioning, cannot be applied. Predicting phase fraction in Q&P steels with consideration of phase transformation during partitioning has also been investigated by some researchers[4, 5]. Z. Dai et al.[4] suggested a model regarding phase transformation during partitioning as the movement of martensite/austenite interfaces, while S. H. Kim et al.[5] suggested a different model regarding it as bainite formation. However, these studies have a limitation in that they cannot predict the trend of decreasing retained austenite fraction as the quenching temperature decreases. One possible reason for this limitation is that both studies did not

adequately reflect the carbon distribution inside the multi-phase Q&P microstructure.

In this study, we introduce a new model for the phase fraction of Q&P steels with consideration of the carbon distribution between phases and the phenomenon of bainite transformation stasis. For the database, eight different steel samples were fabricated using a commercial vacuum induction-melting (VIM) furnace and hot-rolled to a thickness of 13 mm after homogenization at 1200 °C. The chemical composition of each sample was in the range of 0.15-0.45 wt%C, 1.5-4.5 wt%Mn, 0.5-1.5 wt%Si, 0.0-1.0 wt%Al, and 0.0-0.8 wt%Cr. The primary martensite fraction as a function of quenching temperature was obtained from dilatometry curves of quenching and reheating. Four different quenching temperatures were selected for each sample according to its martensite start (Ms) temperature and partitioning temperatures were set to be 350, 400, or 450 °C. After Q&P heat treatment, the retained austenite fraction was evaluated from the integrated intensities of (111)γ, (110)α, (200)γ, (200)α, (220)γ, (211)α, (311)γ, and (220)α peaks from the XRD profile, and the carbon content in retained austenite was evaluated from the diffraction angle of (111)γ, (200)γ, (220)γ, and (311)γ peaks. From the obtained data, the carbon content in primary martensite was derived as a function of quenching temperature and partitioning temperature. Based on the database, we developed a new model for the phase fraction of Q&P steels consisting of martensite fraction prediction with a data-based model and bainite fraction prediction with the modified-GEB model[6]. The prediction result of the new model is in better agreement with the measured data and also shows a similar trend of retained austenite with decreasing quenching temperature to the measured trend.

REFERENCES

[1] J.G. Speer, D.V. Edmonds, F.C. Rizzo, D.K. Matlock, Curr. Opin. Solid State Mater. Sci. 8, 219 (2004)

[2] M.J. Santofmia, L. Zhao, R. Petrov, C. Kwakernaak, W.G. Sloof, J. Sietsma, Acta Mater. 59, 6059 (2011)

[3] F. HajyAkbary, J. Sietsma, G. Miyamoto, T. Furuhara, M.J. Santofmia, Acta Mater. 104, 72 (2016)

[4] Z. Dai, R. Ding, Z. Yang, C. Zhang, H. Chen, Acta Mater. 152, 288 (2018)

[5] S.H. Kim, J.H. Kim, J.H. Lee, D.W. Suh, J.S. Lee, Met. Mater. Int. 28, 2059 (2022)

[6] S.H. Kim, J.H. Kim, K.S. Park, Y.R. Im, J.H. Lee, D.W. Suh, J.S. Lee, Calphad 70, 101804 (2020)

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마이크로 단위 금속 3차원 구조체 제조 및 극한환경 변형 거동 연구

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Fabrication of metallic 3-dimensional micro-architectures and their deformation behavior under extreme conditions

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ABSTRACT

Mechanical metamaterials characterized by their specially designed 3-dimensional structures exhibit high thermal dissipation, specific strength, and energy absorption capabilities. Advances in additive manufacturing have reduced the size scale of these 3-dimensional architectures to the micrometer range. Previous studies have reported that materials at this scale may exhibit the size-related phenomenon of "smaller is stronger," but these studies primarily involved simpler geometries such as particles, pillars, and wires.

In this study, we utilized a novel micro-additive manufacturing process, localized electrodeposition in liquid (LEL), to fabricate copper microlattice structures. The deposition was performed in a voxel-by-voxel manner, allowing for the additive manufacturing of complex 3-dimensional architectures like microlattices. The near-ideal connectivity between the nodes and struts of the microlattice was confirmed by nanocomputed tomography (NanoCT). Additionally, optimized LEL process parameters—such as potential, voxel diameter, and voxel overlap—resulted in smooth surfaces and a microcrystalline grain structure with a high fraction of nanotwin boundaries, as revealed by electron backscatter diffraction and transmission electron microscopy analysis.

The deformation behavior and mechanical properties of the microlattices were investigated via in situ SEM compression tests. Given that the promising applications

for microlattices involve extreme loading conditions (a wide range of strain rates and temperatures), compression tests were conducted at strain rates of 0.001–100 s^{-1} and temperatures of 25°C and −150°C using a piezoelectric actuator-based micromechanical tester. The copper microlattices exhibited clear temperature and strain rate-dependent deformation behavior. To explain these unique dependencies, systematic compression tests of copper micropillars were also conducted. Microstructural analysis of the micropillars post-compression revealed a shift in deformation mechanisms from dislocation slip at 25°C to mechanical twinning at −150°C. Ultimately, the temperature and rate-dependent deformation behavior of the microlattices could be explained based on these mechanisms.

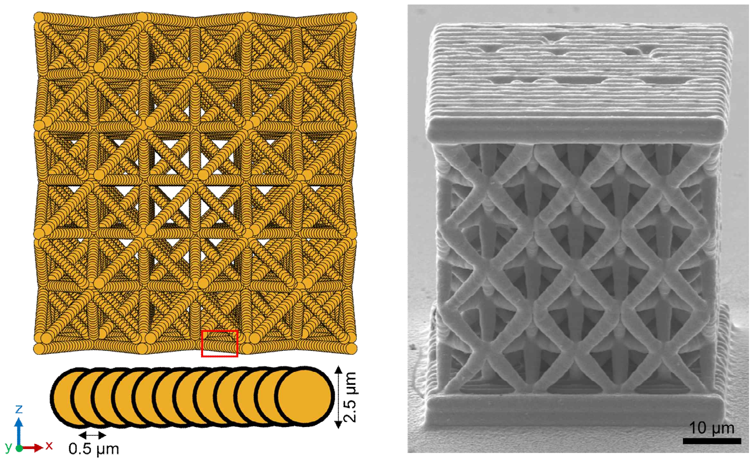

Figure 1. Discretized voxel locations used to print microlattice and SEM image of as-fabricated copper microlattice.

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계층구조 형성에 따른 다공성 금의 기계적 강도 분석

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Study on mechanical behavior of nanoporous gold by inserting hierarchical structure

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ABSTRACT

다공성 금 (nanoporous gold, NPG)은 뼈대를 이루고 있는 금 리가먼트 (Au ligaments)와 기공 (pores)으로 이루어진 나노 크기의 이중 연속 구조 (bi-continuous structure)로써 높은 비표면적 특성과 생체 적합성, 화학안정성으로 인해 촉매, 센서, 엑추에이터와 같은 높은 표면 반응성을 요구하는 분야에서 각광받고 있다. 최근 다공성 금의 리가먼트 구조에 또 다른 다공성 구조가 형성되어 계층구조를 이루는 다공성 구조인, 계층구조 다공성 금 (hierarchical nanoporous gold, HNPG)이 개발되었다. 기존에 존재하는 다공성 금의 구조에 추가적인 기공이 삽입되었기 때문에, 기존의 NPG에 비해 더 높은 비표면적 특성과 낮은 상대밀도 특성을 보인다. 이로 인해 더 가볍지만 더 빠른 표면에서의 반응성을 보인다는 장점이 있어 구조재료 및 기능재료용 다공성 재료에 대한 차세대 재료로 각광받고 있다. 하지만 실사용을 위한 HNPG의 신뢰성 확보를 위한 기계적 물성 분석에 대한 연구는 미비하며, 같은 상대밀도를 가지는 NPG에 비해 계층구조가 기계적 거동에 어떤 영향을 미치는지에 대한 분석이 필요하다. 이러한 점에 착안하여, 본 연구에서는 동일한 상대밀도를 가지는 NPG와 HNPG 샘플을 제작한 뒤, 필라 압축시험을 통한 기계적 물성 및 거동 분석 연구를 진행하였다. 동일한 금-은 모합금을 이용하여 디얼로잉 조건 제어를 통해 NPG와 HNPG 샘플을 제작하였으며, FIB 기법을 통해 가공된 마이크로-필라 시험편을 이용하여 필라 압축 실험을 진행함으로써 기계적 물성을 확인하였다. 나아가, 제작된 HNPG에 대한 열처리를 진행하여 상위구조의 리가먼트 크기 (upper-level ligament size)는 일정하게 유지시킨 채 하위구조 리가먼트 크기 (lower-level ligament size)를 제어함으로써 약 10 nm, 30 nm, 50 nm의 하위구조 리가먼트 크기를 가지는 HNPG를 제적하였다. 이를 통해, HNPG의 하위구조 리가먼트 크기

에 대한 크기효과 (size effect)를 분석하였다. 또한, 전기화학 환경 속에서 실시간 압축실험을 진행하면서 가해지는 전위에 따른 기계적 거동 변화를 분석함으로써, NPG와 HNPG의 전기화학에 의한 표면 변화 반응성을 분석하였다. 그 결과, (1) HNPG에서 NPG보다 높은 압축강도 (10% 변형률 기준)를 보였고, (2) 전기화학에 의한 OH- 흡착층으로 인해 변화는 압축 유동 응력이 HNPG에서 더욱 뚜렷하게 나타났으며, (3) 압축강도와 OH- 흡착에 의한 응력 변화에 대해 HNPG 하위구조 리가먼트 크기 효과 (lower-level ligament-size effect)를 확인하였다.

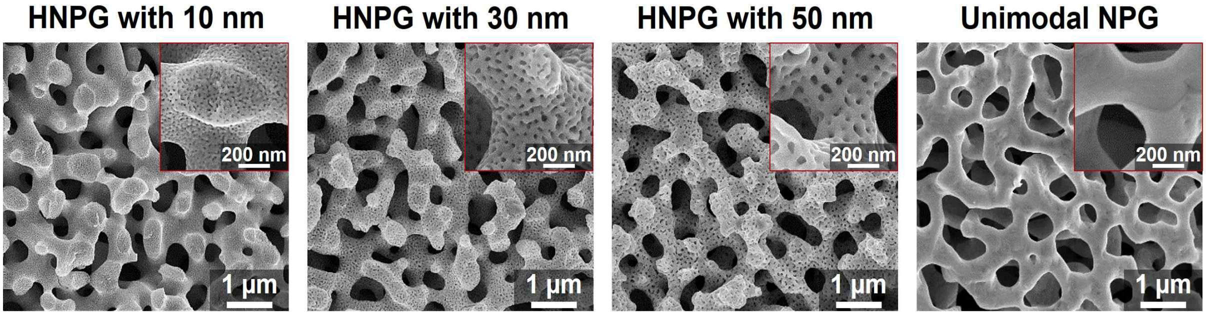

그림 23. 금-은 모합금에 대한 디얼로잉 공정을 통해 제작된 HNPG와 NPG의 SEM 이미지. HNPG에 대한 열처리를 통해 하위구조 리가먼트 크기를 10 nm, 30 nm, 50 nm으로 제어함.

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적층제조된 고엔트로피 합금의 미세역학 거동 및 수소의 영향 연구

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Micromechanical Behavior of an Additively Manufactured High-Entropy Alloy and the Hydrogen Effects on It

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ABSTRACT

The combined effects of pre-straining and hydrogenation on the local deformation behavior of laser-powder bed fusion (L-PBF) processed CoCrFeNi high-entropy alloy (HEA) samples were explored. To analyze the influence of pre-straining, both global pre-strains (imposed using interrupted tensile tests) and local strain levels (estimated using digital image correlation measurements) were employed. It was revealed that pre-straining, which increases the dislocation density in the HEA, does not enhance the hydrogen effects on the micromechanical performance of the L-PBF HEA. To understand this, the trapping behavior of diffusional hydrogen was investigated in detail through thermal desorption spectroscopy (TDS) combined with the Ag decoration technique. The results are discussed regarding the hydrogen content and trapping sites in the L-PBF HEA.

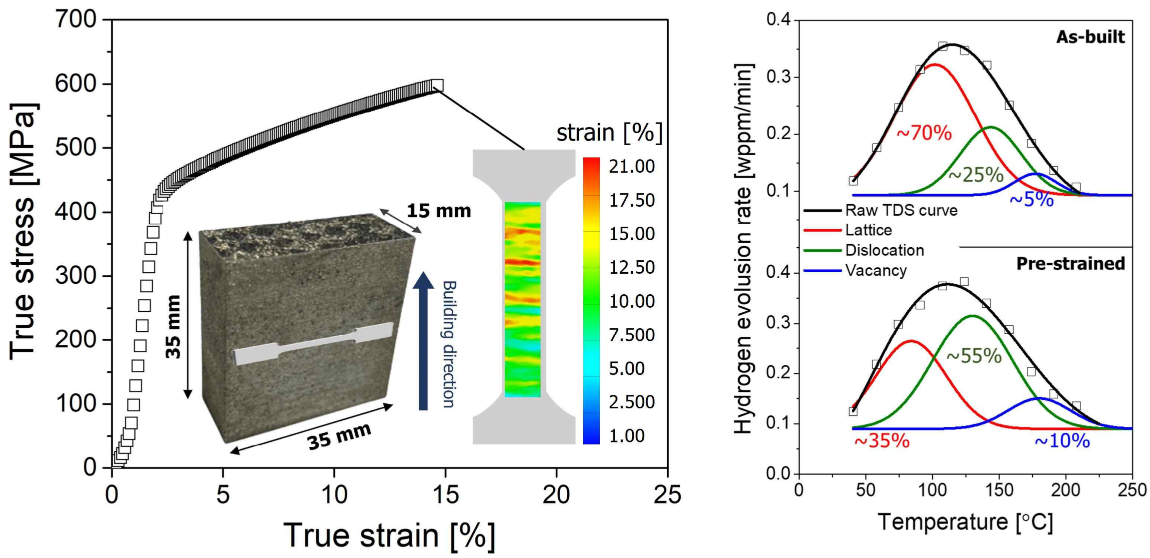

Figure 1. True stress-strain (15% global true strain) curve with local strain distribution (left) and direct comparisons of deconvoluted TDS curves in as-built and pre-strained sample (right).

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나노스크래치 시험법을 활용한 나노스케일 접합력 분석 기술 및 응용 사례

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Nanoscale Adhesion Analysis Technologies using Nanoscatch Test

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ABSTRACT

첨단 제품들이 소형화, 복합화, 다기능화가 되어감에 따라 제품을 구성하는 소재의 종류가 다양해지고 크기/두께는 작아지고 있다. 이러한 산업과 소비자들이 요구하는 특성과 크기를 만족하기 위해 기존에 나누어져 있는 여러 소재들을 나노스케일로 다층으로 쌓아서 하나의 부품 및 제품을 제조하는 방법이 널리 사용되고 있다. 다층의 부품 및 제품은 필연적으로 다수의 계면(interface)를 가질 수밖에 없으며, 두 층의 소재가 분리되는 박리(delamination) 현상이 다수의 계면 중 단 하나의 계면에서 발생하더라도 전체 부품 및 제품의 불량으로 이어지게 된다. 따라서 나노스케일 소재들을 다층으로 쌓는 방법은 기능 향상 및 소형화에는 유리하지만 신뢰성 측면에서는 불리할 수밖에 없다.

대형 구조재료에서 언급되는 weakest link 이론과 마찬가지로 다층으로 구성된 부품 및 제품은 박리가 가장 쉽게 발생하는, 즉 접합력(adhesion)이 가장 약한 weakest interface 결정이 필수적이다. 계면의 접합력을 측정하는 방법들로는 Double cantilever beam test, Peel test(T-Peel 등), Pull-off test, Cross-hatch test, Nanoscratch test 등이 있다, 접합력을 분석하는 기본 원리는 두 층(또는 그 이상)으로 구성된 재료에 인위적으로 박리를 발생시켜서 박리가 발생하는 시점의 힘과 변위를 사용하여 정량적인 또는 정성적인 접합력을 유도하는 것이다. 이때 인위적인 박리를 발생시키기 위해 뜯어내는 방식으로 힘을 주거나(DCBT, Peel, Pull-off 등) 날카로운 형상의 도구(indenter, stylus 등)를 사용하여 긁어내는 방식으로 힘을 주는 방식이 주로 사용된다. 뜯어내는 방식의 시험법들은 표준화가 잘 되어 있고 정량적인 값을 제공해주는 장점을 가지고 있으나 뜯어내기 위

해서 시료의 끝부분을 미리 박리시켜야 하며 층의 두께가 얇을수록 박리 대신 층 소재 자체가 찢어지는 문제가 있다. 또한 시편 형상이 정해져 있고 전용 지그도 제작해주어야 하며 3층 이상의 다층 소재에 대해 실험하기가 어렵기 때문에 나노스케일 다층 소재의 접합력 분석이 어려운 단점이 있다. 이에 반해 긁어내는 방식들은 시편에 대한 사전 준비가 불필요하며 시편 형상도 자유롭고 긁는 하중을 낮추면 나노스케일 소재의 접합력을 분석할 수 있다. 또한 긁는 동안의 깊이, 수평하중, 스크래치 트랙 변화 등을 서로 동기화하면 다층 소재에서의 각 계면에서 발생하는 변화를 확인할 수 있기 때문에 다층 소재의 접합력 분석을 통한 weakest interface 도출도 가능하다. 그러나 분석하고자 하는 다층 소재에 따라 실험 조건, 실험 방법, 분석 방법 등이 달라지기 때문에 표준화가 되어 있지 않고 결과 해석을 위해 많은 노하우가 필요하다는 문제점으로 인해 아직 널리 사용되고 있지 않다. 이에 본 발표에서는 대표적인 긁어내는 방식의 접합력 분석 방법인 나노스크래치 시험법의 원리에 대해 소개하고 이를 활용한 다양한 사례들을 통해 나노스크래치 시험법의 효용성에 대해 살펴보고자 한다.

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적층제조된 316L 스테인리스강 격자구조의 전단변형 거동

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Shear Deformation Behavior of Additively Manufactured 316L Stainless Steel Lattice Structures

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ABSTRACT

With the development of additive manufacturing, lattice structures have emerged as a disruptive technology across various fields, including aerospace, automotive, and defense. Lattice structures exhibit exceptional properties for lightweight and energy absorption capacities, especially under compressive loads. However, the lack of experimental data on complex loads, such as shear properties of lattice structures, poses challenges to their broader application across different load types. This study aims to analyze the shear deformation behavior of lattice structures and compare them with their compressive properties, enabling the safe design of lattice structures for various load applications. To achieve this, 316L stainless steel lattice structures were fabricated using additive manufacturing in three different geometries: body-centered cubic (BCC), face-centered cubic (FCC), and octet truss (OCT), all at the same relative density. The lattice geometries were compared for their mechanical properties and deformation mechanisms under the two types of loading using DIC and FEM analyses, compression and shear tests. It was found that the mechanical properties of the lattice structures under compression and shear loading were varied depending on the geometry, showing that each lattice geometry has a unique

load-bearing capacity that exhibits superior mechanical properties. Furthermore, under shear loading, the struts of the BCC lattice structure showed a bending dominated deformation mode due to the rotation of the nodes, whereas the struts of the FCC and OCT structures presented a compression and tension dominated deformation mode. As a result, the BCC lattice specimens showed a higher shear energy absorption capacity than the other specimens and were capable of bearing higher loads. In addition, the FCC specimens showed lower shear energy absorption. The OCT specimens presented a uniform strain distribution under both compression and shear loading and showed compliant performance. The shear deformation behavior of various lattice structures has been evaluated by considering both geometrical and local strain distribution aspects. Implications for optimization guidelines and potential improvements were also discussed. These results can be used for research and development of the shear properties of lattice structures, the safe design of lattice structures, and industrial applications.

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접착방법에 따른 유연기판 위 금속배선의 기계적/전기적 굽힘피로 특성 평가

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Estimation of pile-up height during spherical indentation using Equivalent-Volume model

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ABSTRACT

The rapid growth of the light and flexible electronic devices industry has sparked significant research interest in flexible elements. Unlike conventional electronic devices, these devices, which use flexible substrates, face challenging environmental conditions and undergo extreme mechanical deformation throughout their life cycle. Mechanical reliability is thus a critical property for these devices, prompting substantial research efforts to enhance it. In this study, we present four distinct adhesion methods between substrates aimed at altering the mechanical behavior of thin films on flexible substrates. To evaluate their effectiveness, we conducted bending fatigue tests, applying a maximum strain of 2%, while continuously monitoring real-time changes in electrical resistance. Additionally, we used finite element analysis to estimate the strain experienced by the thin film on the flexible substrate. The results of the bending tests demonstrated a dependency on the adhesion methods employed, and the finite element analysis provided insights into the underlying reasons related to strain distribution.

주요결과요약

본 연구에서는 접착방법에 따른 유연기판 위 금속배선의 기계적, 전기적 특성을 평가하였다. 두께 125 μm PI 기판 2개를 총 4가지 방법으로 접착하였고, PI/PI 기판 위에 구리배선을 1 μm로 증착하였다. 그리고 굽힘변형율이 최대 2%가 되도록 외부 굽힘과 내부굽힘으로 분류하여 실험을 수행하였다. 또한 굽힘시험 시 시편 내부의 응력분포를 살피기 위하여 유한요소해석을 함께 수행하였다. 굽힘시험과 유한요소해석 결과, 외부, 내부 굽힘 모두에서 전체, 테두리, 가로 부분, 세로 부분 접착 순으로 전기저항 변화율과 굽힘변형률이 낮아지는 경향을 보인다. 이는 휘어진 시편의 첨단부분의 응력이 접착되어 구속된 유연기판의 면적과 분포에 따라 집중되는 정도가 달라지기 때문이다. 유한요소해석 결과 접착되어 있지 않은 기판의 사이가 벌어지며 S자 형태로 변형하여 첨단 부분의 응력집중을 완화시키는 것으로 설명된다. 이는 전 면적이 접착되어 있지 않은 3가지 방법으로 제작한 시편에서 공통적으로 나타난다. 결론적으로 굽힘피로에 의한 파손을 줄이기 위해서는 굽힘방향과 수직으로 접착면적을 줄이는 방향으로 시편 및 부품을 설계하는 것이 타당할 것으로 판단된다.

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적층 공정 매개 변수의 함수로 박막의 미세 구조 변화에 관한 몬테카를로 시뮬레이션 연구

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A Monte Carlo simulation study on the microstructure evolution of thin films as a function of deposition process parameters

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Abstract

The evolution of the microstructure of the deposited metallic thin film is predicted using a Monte Carlo Potts model. This model incororates two primary dynamic mechanisms for microstructural evolution: 1) spin exchange, which mimics the diffusion of matters, and 2) spin flip, which represents the grain growth. The detailed explanation on the Potts model, including the relaization of the deposition process, is given. The main goal of this study is to obtain the meaningful predictions on the microstructral characrteristics of the thin film during deposition as a function of the controlling process parameters. Since a complete control of the processing parameters for the thin film deposition is challenging to accomplish, it is sometimes diffcult to assess the process-microstructure relationship both quantitatively and qualitatively only based on a series of deposition experiments. The key processing parameters we focus on here are the deposition rate of the monomers on the subtrate, the temperature of the system (assigned to be constant), and the kinetic energy of the monomers to be deposited. Even thoug isotropic grain boundary and surface energies are assumed virtually for the materials during the simulation, the microstructure characteristics of the thin film such as the nucleation density, grain size and grain

morphology are found to be very sensitive to the processing parameters. Also, we found that the average grain size of the thin film is a function of film thickness. The resultant microstructural characteristics obtained from the proposed model are also found to be analogous to the predictinos from the structure zone model.

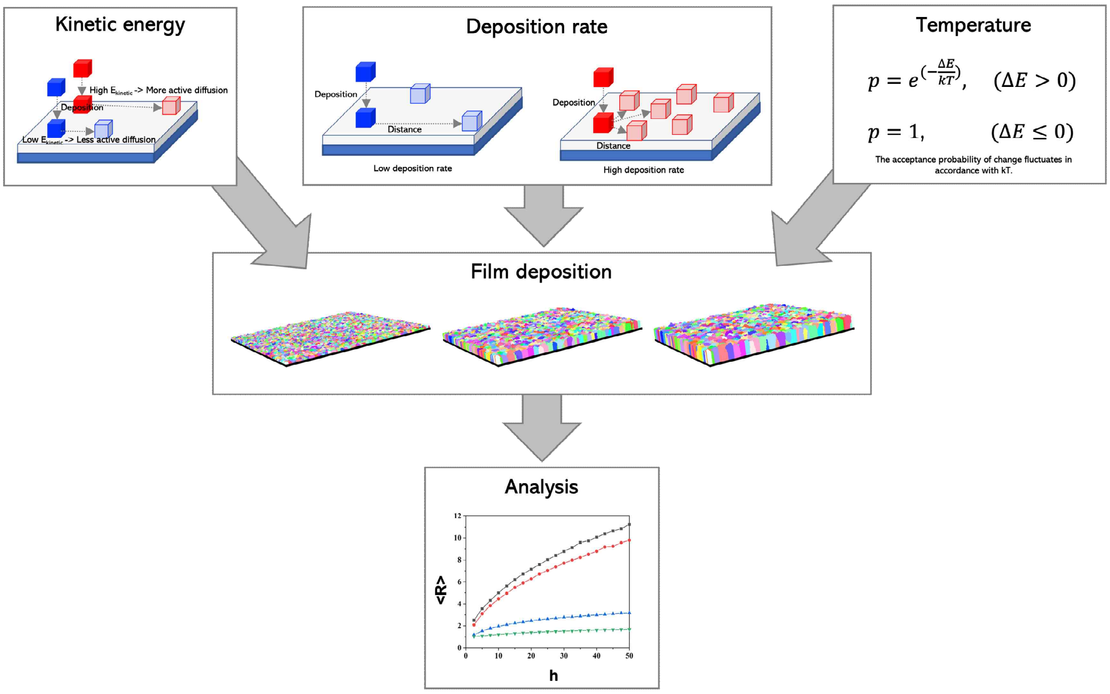

Figure 25 This diagram the prediction process for thin film microstructural evolution

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유연 초민감 변형률 센서를 활용한 구조물 안전 모니터링

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Monitoring of Structural Safety Using Highly Strain-Sensitive Flexible Sensor

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ABSTRACT

실시간 변형도 진단 및 대응 기술은 기계적 센서를 통해 일상적인 물체에서 수집된 다양한 데이터가 인터넷과 연결되어 공유됨으로써 다양한 분야에서 활용되고 있습니다. 전통적인 구조적 결함 진단 및 대응 방법들은 사고 후 대응에 중점을 두었지만, 이제 이 실시간 모니터링 기술을 적용함으로써 새로운 안전 진단 플랫폼을 구축할 수 있습니다. 본 연구에서는 나노 스케일의 균열을 의도적으로 유도하여 높은 민감도로 미세 변형을 측정하도록 설계된 박막 금속 필름 스트레인 센서를 사용했으며 구조물의 미세 변형 및 균열 확장을 감지하고 진단하는 기술을 소개합니다. WiFi, Bluetooth, LoRa와 같은 다양한 무선 통신 기술을 적용하여 구조물의 실시간 스트레인 모니터링 데이터를 무선으로 쉽게 전송하고 받을 수 있습니다. 구조물 내의 미세 균열 확장으로 인해 변화하는 외부 표면 스트레인을 분석하여, 실시간 모니터링 데이터를 기반으로 구조적 결함 발생 전에 물체의 안전성을 평가하는 플랫폼을 제안합니다.

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나노카드보드의 변형 거동 및 응용

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Mechanical behavior of nano-cardboard and its application

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ABSTRACT

Nano-cardboard structures, ultralight panel based on nanolattice structure, are shell structures that consist of two face plates held together by hollow tubes that serve as ligaments. These structures are fabricated entirely using thin films with thicknesses on the order of 100nm or less. As a result of their geometry, nano-cardboard structures have a very low density and are ten times stiffer than aerogels or nanolattices of the same densities (5-20 kg/m^3). Additionally, they exhibit recoverable deformation similar to nanolattices and have a low thermal conductivity similar to aerogels. Nano-cardboard structures are light enough to be levitated by photophoretic forces, they can serve as substrates for sensors, and may be of interest in geoengineering applications. Here, we describe a low-cost and fast process for fabricating scalable nano-cardboard structures. The fabrication process relies on inexpensive silicon wafers that are patterned by means of deep reactive ion etching to form sacrificial scaffolds. The sacrificial scaffolds are then uniformly coated with a thin ceramic layer using atomic layer deposition. In a final step, the silicon is etched away through small openings in the top face using XeF2 gas, leaving a ceramic nano-cardboard with dimensions comparable to those of the original silicon wafer. Using this approach, nano-cardboard can be fabricated from many different ceramics and metals, with no limitation on the size of the nano-cardboard other than the wafer dimensions. We have analyzed the mechanical behavior of nano-cardboard with various periodic ligament patterns including a hexagonal and basket-weave patterns using finite elements. The nano-cardboard stiffness, buckling load, and post-buckling

behavior depend sensitively on both the ligament pattern and dimensions, allowing optimization of the structure for maximum specific stiffness and strength. Because of their macroscopic dimensions, nano-cardboard structures can be tested relatively easily using a range of different mechanical techniques. Here, we present results of bending experiments on nano-cardboard structures using nano-indentation. After understanding the deformation behavior of nano-cardboard, we applied the photophoretic effect to nano-cardboard to propose a structure capable of permanent levitation using the temperature gradient within the structure caused by sunlight. Through actual experiments, we demonstrated that the proposed structure can achieve levitation with light intensity below 1 sun. This photophoretic levitation device can be proposed as a levitation device for environments where traditional propeller systems are difficult to apply due to low air density, such as the upper atmosphere or Mars.

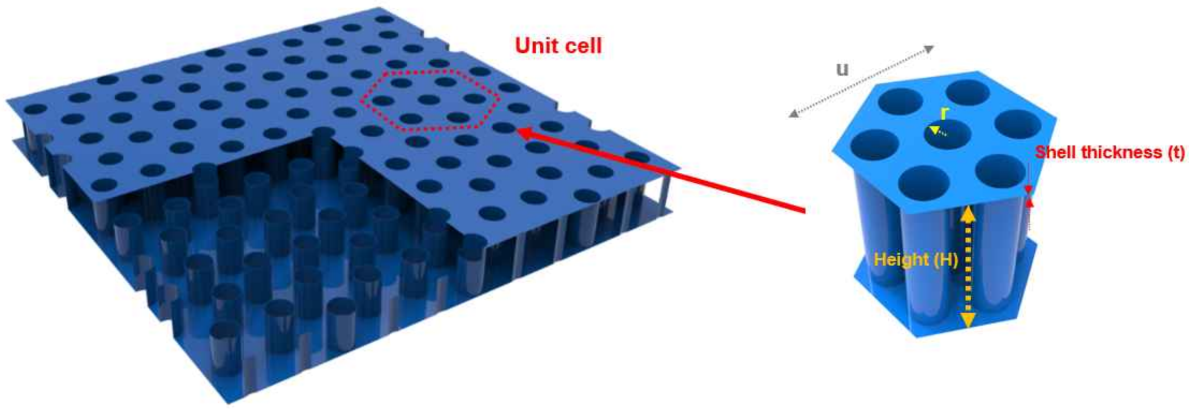

Figure 1. Schematic diagram of nano-cardboard structure with hexagonal pattern.

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전위 상호작용 분석을 통한 알루미늄-그래핀 나노층 복합체의 강화 메커니즘 규명

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Elucidating Toughening Mechanisms in Aluminum-Graphene Nanolayered Composites through Dislocation Interaction Analysis

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ABSTRACT

Two-dimensional (2D) graphene, renowned for its outstanding mechanical properties, has been extensively studied as an interlayer in metal or metallic glass composites to enhance their performance. Graphene's high in-plane intrinsic strength enables it to effectively block dislocations, preventing the formation of slip steps and thereby reinforcing the composite, with substantial reinforcement observed in composites where graphene directly interacts with metals, such as at Cu-graphene or Ni-graphene interfaces. However, the thick native oxide passivation layer formed on aluminum prevents direct bonding between the metal and graphene, and there is few analysis through dislocation movements as to whether graphene can strengthen the composite even in the presence of amorphous alumina layer. Herein, we elucidate the toughening mechanism of Al-graphene multilayers through dislocation interaction at the interface. The strengthening effect of graphene is inhibited due to dislocations interacting primarily with the native aluminum oxide rather than the graphene, a dislocation interaction at the interface was analyzed using high-resolution transmission electron microscopy (HRTEM). This interaction results in negligible improvement in the mechanical properties of Al-graphene multilayers compared to Al multilayers. Conversely, employing a capping layer such as silver to suppress the formation of the alumina layer allows for direct binding between crystalline silver and

graphene (Al-Ag-Gr), leading to a remarkable strength enhancement in mechanical properties due to strengthening effect of graphene. This study reveals that achieving the reinforcing effects of graphene necessitates the formation of interfaces where dislocations can directly interact with graphene. This research provides deeper insights into the integration of 2D materials in composites and is anticipated to have broad applications across various industries utilizing aluminum and graphene.

제 38 회 첨단구조재료 심포지엄

8월 29일 [목]

제 3 발표회장

- Session 1
- Session 2

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VCoNi 중엔트로피 합금과 17-4PH 스테인리스강의 그린 레이저 용접부 미세조직 및 기계적 특성

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Microstructure and mechanical properties of green laser welds of VCoNi medium-entropy alloy and 17-4PH stainless steel

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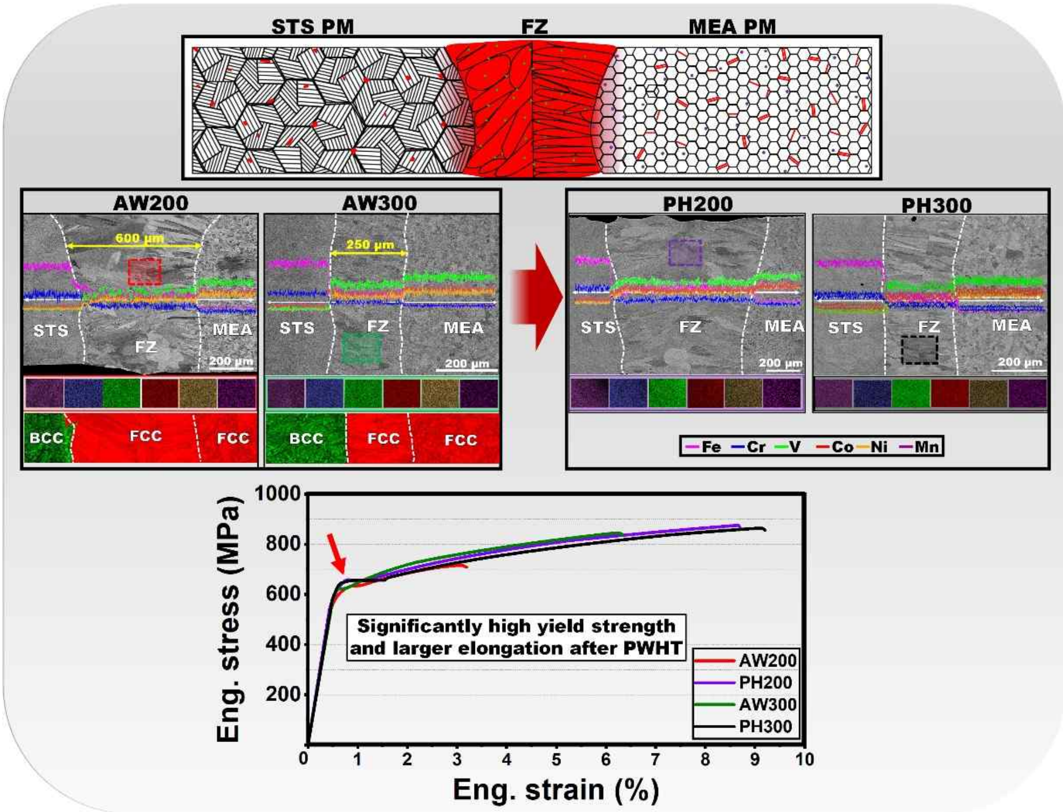
ABSTRACT

The integration of advanced alloys, such as the VCoNi medium-entropy alloy (VCoNi-MEA), which possess remarkable tensile strength (> 1 GPa) and superior ductility, necessitates the employment of dissimilar joints in engineering structures. This investigation pioneers the dissimilar joining of VCoNi-MEA and 17-4 precipitation hardening stainless steel (17-4 PH SS) utilizing state-of-the-art green laser beam welding (LBW). To evaluate and optimize the experimental parameters, welding speeds of 200 mm/s and 300 mm/s, along with post-weld heat treatment (PWHT), were employed. The study successfully produced high-quality welded joints exhibiting a single-phase face-centered cubic (FCC) structure in the fusion zone (FZ), with minimal precipitates (< 1.6%) and an absence of visible cracks. The LBW process demonstrated effective low-heat input characteristics, evidenced by a significantly narrow heat-affected zone (HAZ). Control over the FZ width and grain size was achieved, measuring 600 μm and 112 μm at the lower welding speed and 250 μm and 49 μm at the higher welding speed, respectively, which are significantly lower than previously reported values. The as-welded joints exhibited a yield strength (YS) of ~620 MPa and an ultimate tensile strength (UTS) of up to 845 MPa, which improved to approximately 645 MPa and 875 MPa, respectively, after PWHT. This enhancement in mechanical properties is primarily attributed to lattice friction induced by the addition of vanadium. Furthermore, PWHT enhanced the ductility

of the joints, increasing from 3.5% to 8.6% (low-speed) and from 6.3% to 9.2% (high-speed). The reduction in crystallographic orientation achieved through higher welding speeds and PWHT was identified as a significant factor contributing to the improved mechanical properties. Slip-based deformation mechanisms were predominant across all conditions, characterized by crystallographically aligned slip bands. Interactions between existing and newly formed slip bands resulted in a dense dislocation network, which was crucial for the enhanced elongation observed after PWHT. Thermodynamic parameters elucidating phase stability in the observed FZs and their contributions to superior YS were calculated and thoroughly discussed.



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순수 타이타늄의 극저온 인장 변형기구 및 serration 거동 연구

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Unveiling Tensile Deformation Mechanism and Serrated Flow of Commercially Pure Titanium at Cryogenic Temperatures

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ABSTRACT

The mechanical properties of metallic materials at extremely low temperatures are essential for maintaining structural integrity in various applications, including fuel tanks, pressure vessels, and aerospace components. On a microscopic level, these properties are influenced by the formation and movement of extended defects such as stacking faults and dislocations. At cryogenic temperatures, the reduced thermal activation energy impacts defect activity, altering the balance between dislocation glide and deformation twinning as the primary deformation mechanisms. One notable phenomenon at these low temperatures is serrated flow behavior, which has intrigued scientists for decades. Titanium, particularly in its pure form, is known for displaying this behavior and is crucial in cryogenic applications. However, the mechanisms driving serrated flow in titanium are not fully understood. This study aims to fill this knowledge gap by examining the deformation behavior of commercially pure titanium at extremely low temperatures. Utilizing a range of mechanical testing methods and advanced characterization techniques, including electron microscopy and in-situ neutron diffraction analysis, this research seeks to offer a thorough understanding of this complex phenomenon. Digital image correlation will be employed to observe deformation behavior at temperatures as low as 15 K, allowing for a detailed analysis of microstructural changes and deformation mechanisms.

Keywords: Cryogenic temperatures; Serrated flow behavior; Commercially pure titanium; Deformation mechanisms; Microstructural analysis

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준안정 철계 중엔트로피합금 용접의 조성적 이질성에 의한 극저온 특성 향상

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Enhancing cryogenic properties via compositional heterogeneity in metastable ferrous medium-entropy alloy welds

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ABSTRACT

As the demand for hydrogen gas ans liquefied natural gas increases, there is a desperate requirement to satisfy the low-temperature characteristics of structural materials for storage and transport containers. Currently, austenitic stainless steels have been used as conventioanl materials due to their excellent cryogenic properties. However, they face issues such as solidification cracking, and sensitization after welding. Therefore, alternative materials should be developed to address these welding problems. High-entropy alloy (HEA), and medium-entropy alloy (MEA), which consist of multi-principal elements without interstital elements, could overcome the limitations of conventional alloys. The aim of this study was to evaluate the indispensable weldability of ferrous MEA for structural materials operating in cryogenic environments. This study revealed that welded ferrous MEA demonstrated superior cryogenic tensile properties compared to the non-welded ferrous MEA. The reason behind the enhancement in strength and elongation at 77 K was systematically elucidated through microstructural deformation mechanisms.

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미세 석출상이 Fe-Cr-Mn-Ni 합금의 강도 및 내식성 향상에 미치는 영향

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Effect of Fine Precipitates on the Improvement of Strength and Corrosion Resistance in Fe-Cr-Mn-Ni Alloy

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Departement of Materials Science and Engineering, Koomin University

ABSTRACT

This study aimed to produce a material with an excellent combination of strength and corrosion resistance using Fe-Cr-Mn-Ni steel. Specifically, it sought to achieve superior properties with low Ni content by controlling the Ni content. As the Ni content increased, the fraction of the σ phase increased, and the best combination of strength and elongation was obtained at a heat treatment temperature of 800°C. Regarding corrosion resistance, higher Ni content resulted in better corrosion resistance. Although relatively good corrosion resistance was achieved at a heat treatment temperature of 100°C, excellent corrosion resistance was also observed at 800°C. Thus, this study aimed to control the fraction and size of precipitates by adjusting the alloy composition and heat treatment conditions to achieve an excellent combination of strength and corrosion resistance.

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다원계 CrCoNiCu 합금 박막의 시효에 따른 내마모 자기윤활 거동

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Wear resistance and self-lubricating behavior by aging treatment in CrCoNiCu medium-entropy alloy films

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ABSTRACT

Most industrial components suffer from wear-related losses, necessitating an understanding and improvement of tribological properties. Since these properties are restricted to the surface, coatings are employed to enhance tribological characteristics. Sputtered films of high- or medium-entropy alloys (HEAs or MEAs) have been reported for notable tribological benefits due to their high hardness and exceptional

wear resistance. However, HEAs or MEAs typically exhibit low friction coefficients only under specific conditions, such as at temperatures above 500 °C, limiting their low friction in environments. Self-lubricating capabilities are required to exhibit low friction in various environments. Soft metals demonstrate self-lubrication due to their low critical shear stress, indicating limitations in low wear resistance.

In response to the challenge of optimizing the tribological performance of soft metal without compromising material hardness, composite materials incorporating self-lubricating phases have been investigated to improve friction-wear properties. This study aims to design a composite film containing a CrCoNi alloy for the reinforcement and Cu for solid lubricants. The CrCoNiCu films were fabricated via sputtering and subsequently aged at 200 °C for 24 h. The as-sputtered film reveals that the sputtering fabrication yields a single face-centered cubic phase enriched with stacking faults and twins due to vapor quenching and increased defective nuclei formation. The aging treatment facilitates the formation of Cu-rich phases, featuring repetitive plate-like structures along twin boundaries by altering diffusion pathways to enhance diffusivity at low temperatures. These films are examined for their mechanical and tribological behaviors through nanoindentation and reciprocal sliding wear tests. Remarkably, the aging treatment increases the hardness of the films by 1.5 GPa and significantly improves their tribological performance, with reductions in friction coefficients and wear loss volumes by 12.1% and 90.1%, respectively. The tribological properties originate from the synergistic effects of precipitation hardening and the lubricating layer, which enhance abrasive wear resistance and inhibit direct contact between sliding surfaces. These findings demonstrate that the aged CrCoNiCu alloy film exhibits an exceptional capacity for superior wear resistance, offering a compelling strategy to navigate the traditional trade-off between wear rate and hardness in the design of advanced engineering materials.

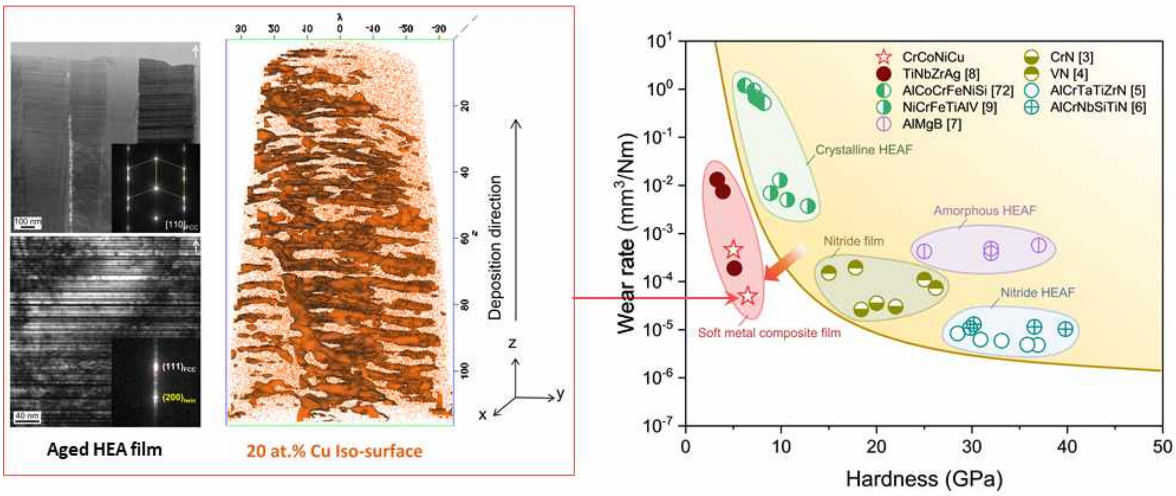

Fig. TEM micrograph, diffraction pattern, and 3-D reconstruction map with an iso-surface of 20 at% Cu for the aged CrCoNiCu alloy film. Comparison of wear rates versus hardness for various films.

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단결정 및 다결정 CrCoNi 중엔트로피 합금 내 수소 확산 및 고용 거동에 대한 격자간 자리와 결정립계의 역할

양대철[1,*], 김기정[1], 이건직[1], 송상윤[1], 백주현[1], 서진유[2], 서성문[3], 김영균[3], 나영상[3], 손석수[1]
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Roles of lattice interstitial site and grain boundary on hydrogen diffusion and trap behaviors in single-and poly-crystalline CrCoNi medium-entropy alloy

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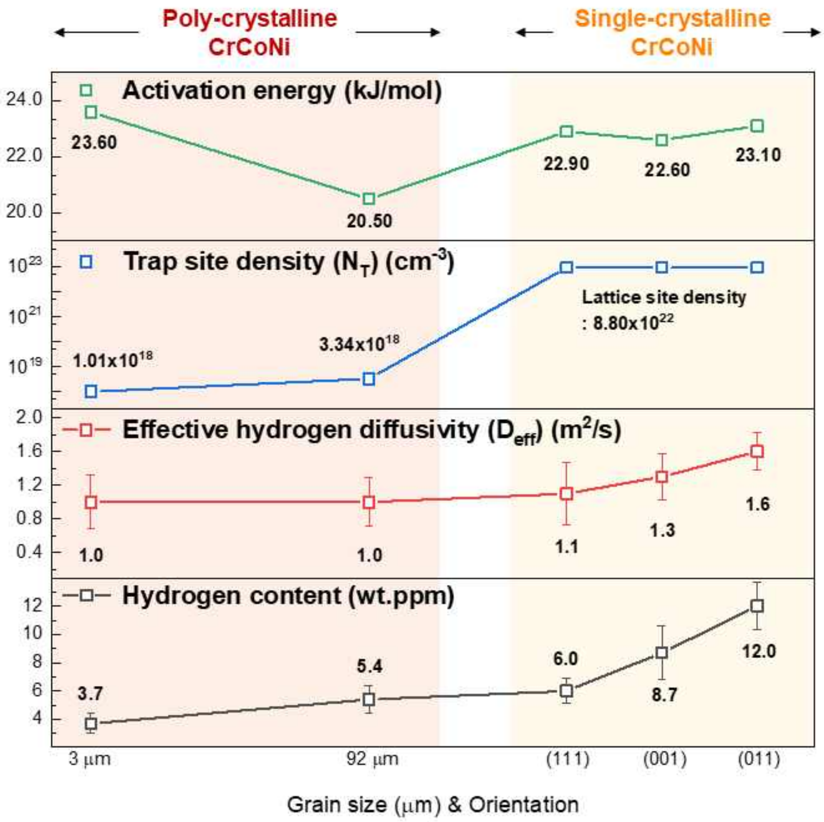
Abstract

Recent research has concentrated on investigating the influence of grain boundaries (GB) and interstitial lattice sites on hydrogen embrittlement (HE). However, clarifying the interactions among GB, interstitial lattice sites, and hydrogen presents challenges due to the complex microstructural factors associated with GB and interstitial lattice sites in hydrogen behavior. Consequently, this study employs single-crystalline and poly-crystalline CrCoNi alloys as model systems to analyze the specific roles of GB and interstitial lattice sites. To comprehensively understand hydrogen behavior, both electrochemical and gaseous hydrogen pre-charging methods are utilized. The hydrogen content, diffusivity, and activation energy are quantified using thermal desorption analysis and hydrogen permeation tests, which elucidate (1) the variations

in hydrogen behavior regarding to the presence of GB, and (2) the changes in hydrogen behavior depending on the crystallographic orientation of the interstitial lattice sites. The results show that GB and lattice sites have similar binding energies for hydrogen trapping. However, the introduction of GB shifts the primary trapping sites from interstital lattice sites to GB. In poly-crystalline alloys, the hydrogen content is governed by the trap site density of the primary trapping sites. Conversely, in single-crystalline alloys, where only lattice sites are present, the crystallographic orientation of the hydrogen-charged plane significantly influences hydrogen content and diffusivity. These insights contribute to a more profound understanding of hydrogen behavior within complex microstructures and suggest strategies for alloy design to enhance resistance to HE.



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중엔트로피 합금에서 적층결함에너지 분석을 통한 전위와 쌍정 변형 고찰

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Dislocation density and yielding, twinning and plastic deformation in a medium entropy alloy

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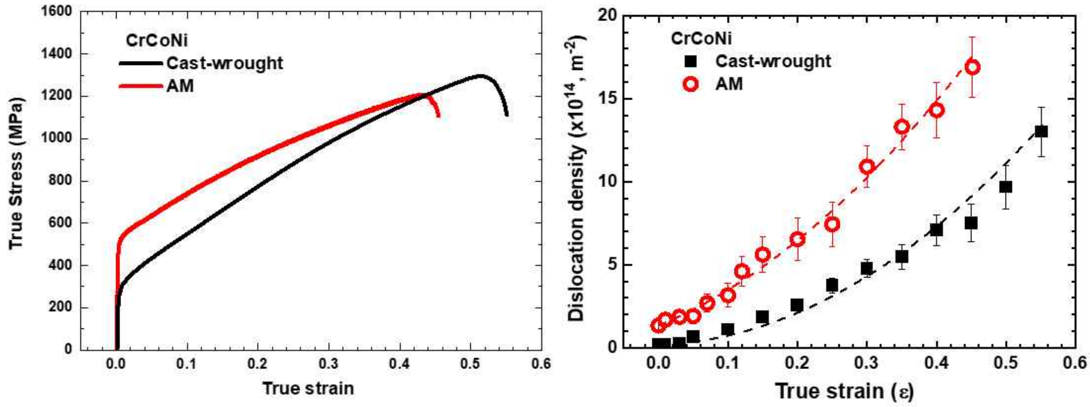
ABSTRACT

Microstructure characteristics and mechanical properties were examined by using EBSD, TEM, and in situ neutron diffraction in CrCoNi medium entropy alloys (MEAs). Higher yield strength (510 MPa) of an additively manufactured specimen (AM) was observed compared to 310 MPa of a conventional cast-wrought specimen (CW). It is considered due to higher initial dislocation density in AM (1.3×10^{14} m^{-2}) compared to that of CW (1.8×10^{13} m^{-2}). Meanwhile, tensile strength (1300 MPa) of CW is higher than AM (1200 MPa). It is likely attributed to higher twin fault probability of CW (2.7%) than AM (1.3%). The stacking fault energy (SFE) suggests the favourable strengthening mechanism of the dislocation slip in AM and twinning in CW, respectively. The strain field of dislocations incorporated model estimated the SFE as 18.6 mJ/m^2 in CW and 37.5 mJ/m^2 in AM MEAs.



Stress-strain curve and dislocation density analyses in additively manufactured (AM) and conventional cast-wrought (CW) specimens in CrCoNi medium entropy alloys

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Enhancing the fatigue resistance of high and medium entropy alloys by manufacturing-driven microstructural developments

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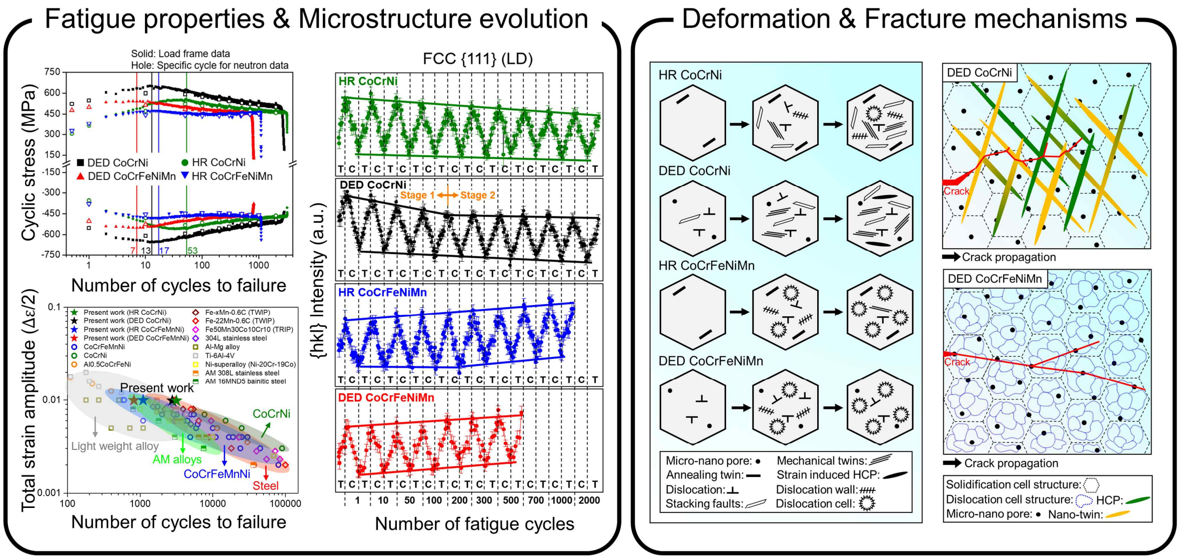
ABSTRACT

Excellent fatigue performance is essential for broader applications of structural materials. In this work, we report a microstructural design that improves fatigue resistance for high and medium entropy alloys fabricated by direct energy deposition and hot-rolling processes. Specifically, we discover that the concurrent evolution of microstructures with fine-structure, including stacking faults, nano-twins and hexagonal-close-packed (HCP) structures, leads to zig-zag fracture that hinders crack propagation under cyclic loadings. These multiple characteristic microstructures improve fatigue resistance, which are attributed to the combination of low effective stacking fault energy and a high capacity for strain energy density. Anisotropic microstructural evolution is driven by the correlation between partial dislocations and the resolved shear stresses depending on the crystallographic orientation relationship. Consequently, stacking faults and nano-twins form prominently in the {111} grains under tension and in the {200} grains under compression. The current work provides an effective method to design advanced alloys for high fatigue resistance through microstructural tuning that controls the stacking fault energy combined by

manufacturing processes.



Graphical abstract: Fatigue properties, microstructure evolution, deformation mechanisms, and fracture mechanisms of additive manufactured high and medium entropy alloys under cyclic loading.

Keywords: Low-cycle fatigue, Stacking-fault energy, Manufacturing process, CoCrFeNiMn, CoCrNi.

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M-MEAM 적층 제조 공정을 이용한 2GPa급 AISI D2 공구강의 제조, 미세조직 및 기계적 특성

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Fabrication, Microstructure and Mechanical Properties of 2GPa Class D2 Tool Steel Manufactured by M-MEAM Additive Manufacturing Process

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ABSTRACT

2GPa class D2 tool steel was manufactured by using metal-materials extrusion additive manufacturing (M-MEAM) process. Subsequent post-heat treatment was then performed in order to control the microstructure and mechanical (tensile, fracture toughness, wear) properties. The as-fabricated M-MEAM D2 exhibited a pearlite structure with a relatively high fraction of low-angle boundaries and a more developed substructure compared to the fully ferrite matrix of the as-fabricated wrought D2. A more uniform size and distribution of carbides was found in the M-MEAM D2. Following post-heat treatment, the matrices of both M-MEAM and wrought materials underwent a transformation into a fully lath martensitic structure, with the addition of sub-micron-scale carbides precipitating. Tensile results demonstrated that heat-treated MEAM D2 exhibited a tensile strength of approximately 2.09 GPa, which was superior to the heat-treated wrought D2 specimens and a better strength-elongation combination than D2 materials produced by metal injection molding. Fracture toughness and wear resistance were also superior than those of conventional process D2 materials. Based on these findings, the deformation, fracture and wear mechanisms of M-MEAM D2 material were also discussed.

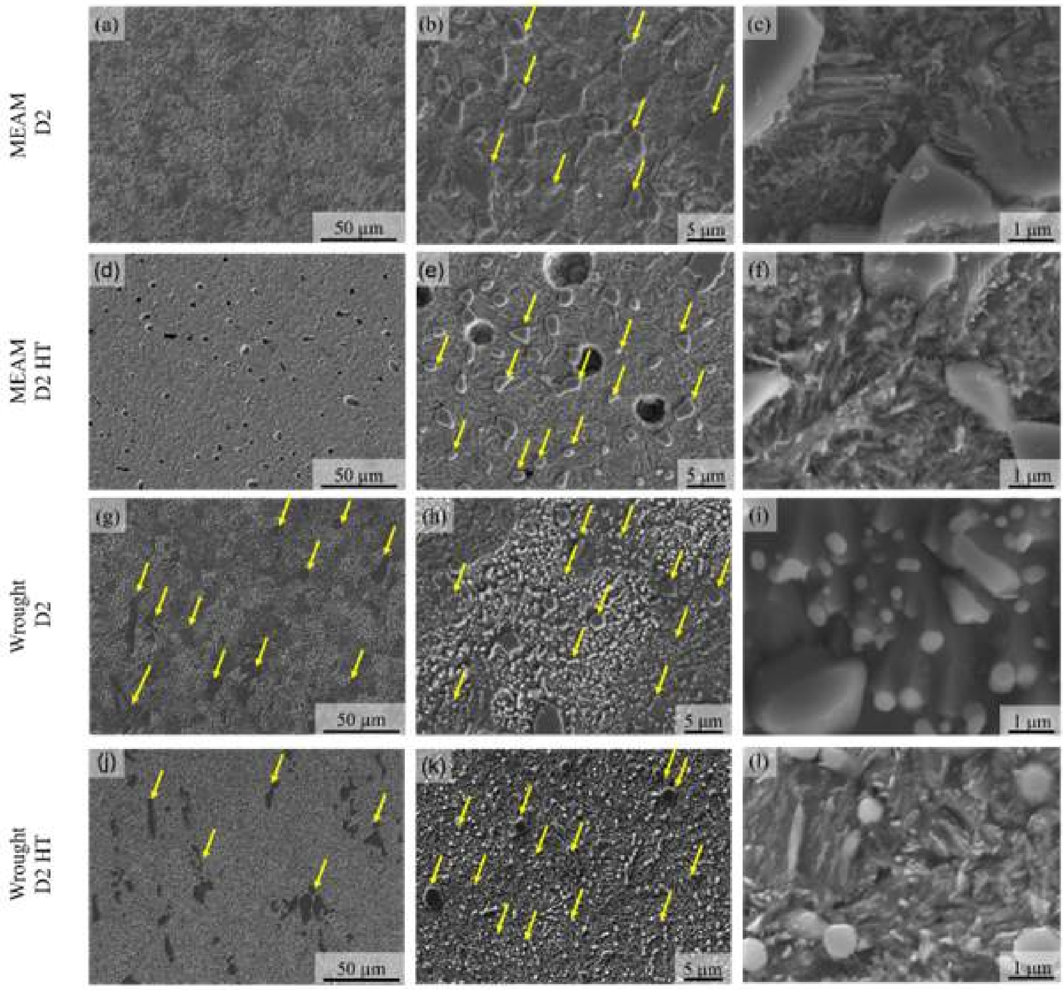

Fig. 1. SEM images showing etched microstructures of (a-c) MEAM D2, (d-f) MEAM D2 HT, (g-i) Wrought D2, and (j-k) Wrought D2 HT with yellow arrows indicating some carbides.

Table 1. Representative tensile properties of MEAM and wrought materials.

	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)
MEAM D2	947.69 ± 5.67	512.14 ± 2.03	13.37 ± 2.18
MEAM D2 HT	2089.15 ± 23.01	1762.15 ± 5.14	1.27 ± 0.01
MEAM D2 HT (w.surfacecrack)	1786.93 ±1.90	1747.02 ±0.08	0.18 ±0.04
Wrought D2	768.82 ± 11.61	353.2 ± 23.23	20.97 ± 1.09
Wrought D2 HT	1951.46 ± 20.42	1813.58 ± 17.22	0.47 ± 0.16

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Nb 첨가 핫스탬핑 마르텐사이트강의 벤딩성형성 향상 기구

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Mechanism for improving bendability in Nb-containing hot-stamped martensitic steel

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ABSTRACT

Hot-stamped martensitic steels are applied to the structural components in vehicles owing to their high strength, excellent crashworthiness, and lightweight properties, which are attributed to the hot stamping process. Hot stamping process is regarded as a unique process to achieve forming and hardening, simultaneously, after the conventional thermo-mechanical processes, i.e., hot rolling and cold rolling. In particular, hot stamping facilitates performing very high strength maintaining the formability of steels. This outstanding property is strongly attributed to prior austenite grain size (PAGS), martensitic microstructure, and fine MX precipitates. Meanwhile, Nb-containing hot-stamped steel with UTSs of 1.5 GPa has been recently developed, which shows better bendability compared to a conventional hot-stamped steel. In this study, the mechanism on the better bendability was investigated especially by in-depth observation using TEM, EBSD, 3D-APT, and micro-specimen tests.

Two cold-rolled sheets (commercial and high-bendable) were used for this study. Both are low-carbon micro-alloyed steels having C, Si, Mn, Cr, Ti, Mo, B, Al. Commercial one is without Nb but high-bendable is with a small amount of Nb.

Microalloying of Nb resulted in a smaller PAG size (7.9 - 8.5 μm) in the high-bendable steel than that (~16.5 μm) in the commercial one. In both steels, the distribution of cementite, precipitated by auto-tempering, was observed in the martensitic matrix. Meanwhile, in the high-bendable steel, fine-sized (20 - 40 nm) and large-sized (~100 nm) (Ti,Nb)(C,N) MX precipitates were observed, and these were

promoted by the addition of Nb. The commercial steel exhibited slightly higher yield and tensile strengths than the high-bendable steel. However, the hardness traverse from surface to surface was significantly different between both commercial and high-bendable steels. The commercial steel exhibited a higher hardness at near the surface than at the center. In contrast, the high-bendable steel exhibited a higher hardness at the center, showing the surface softening. The high-bendable steel performed a notably superior bendability compared to the commercial steel in the mini-scale bending test. This improvement was attributed to homogeneous deformation at the surface, evidenced by uniform distribution of strain within the interior grains. The inferior bendability of the commercial steel resulted from localized deformation at the surface, leading to localized cracking, particularly at PAGB. From the micro-bending test, CRSSs at the PAGB and within the packet were determined in the commercial and high-bendable steels. Both steels exhibited a similar CRSS (~1.7 GPa) at the PAGB. However, within the packet, the commercial steel showed a higher CRSS (~2.05 GPa), whereas the high-bendable steel showed a lower CRSS (~1.51 GPa), providing the evidence of the softer grain interior with a low hardness value. Lower CRSS in the grain interior facilitates deformation compared to at the PAGB, contributing to homogeneous deformation when subjected to a bending load in the high-bendable steel, which corresponds to the result of mini-scale bending tests.

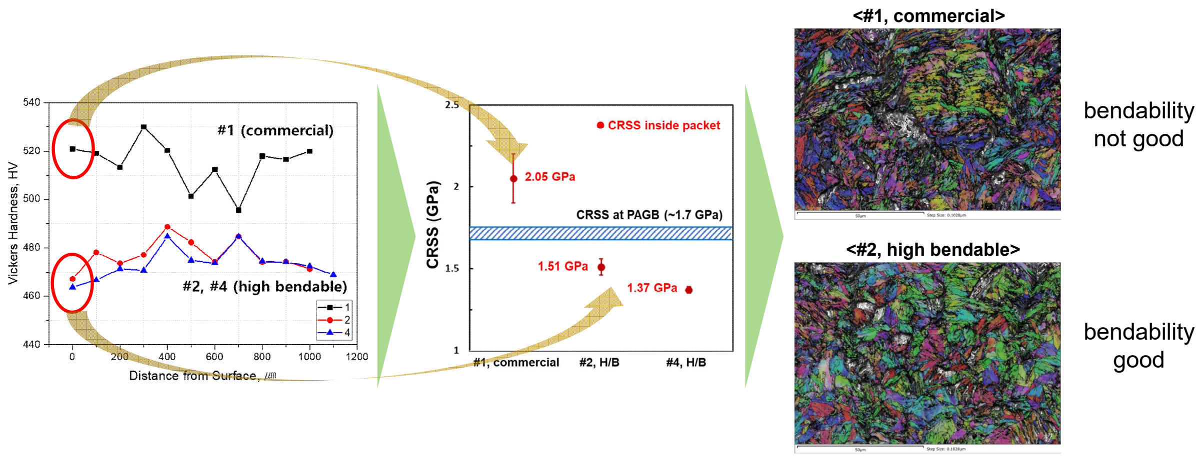

Fig. 1. Mechanism for improving bendability in Nb-containing hot-stamped martensitic steel

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자동차용 고강도 강판의 인장성질 예측 기계학습과 역설계 모델

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Predictive Machine Learning Model of Tensile Properties and Inverse Design of High Strength Automotive Steel Sheets

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ABSTRACT

The Transformation-Induced Plasticity phenomenon in advanced high-strength steels, involving the conversion of retained austenite to martensite during deformation, has been harnessed to delay plastic instability, leading to an excellent balance between strength and ductility. Nevertheless, the challenge of identifying the optimal combination of multi-component alloying chemistry and processing routes to achieve the desired tensile strength and ductility persists. In this study, we developed machine learning models to predict room temperature tensile properties of low-alloyed TRIP-aided steels. This predictive framework involved data augmentation by incorporating missing information and utilizing the CALPHAD approach, followed by validation against literature values. Furthermore, we elucidated the features that influence mechanical properties and microstructure through model interpretability analyses. To further optimize the strength-ductility trade-off, we applied a multi-objective optimization strategy, intending to expand the Pareto-front systematically. Finally, we derived composition-process combinations that yield tensile-strength balance of about 35,000 MPa%, a range consistent with experimentally reported values.

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Segregation engineering기반 컴플렉시온 석출물 제어를 통한 우수한 J-based fracture toughness를 갖는 TRIP-Maraging steel 개발에 대한 연구

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Development of TRIP-Maraging steel with exceptional J-based fracture toughness through the segregation engineering-based complexion precipitation control

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마레이징 강(Maraging steel)은 로켓 엔진 케이스, 잠수함 선체 및 극저온 미사일과 같은 중요한 응용 분야에서 중요한 부품으로 사용되는 중요한 소재이다. 그러나 고강도가 요구되는 환경에서 주로 사용되는 마레이징 강은 강도-연신 trade-off를 극복하지 못하며 취성 특성을 가지고 있다. 따라서 본 연구에서 Intragranular complex compound 석출에 의해 초고강도 특성을 가지는 Martensite 기지를 갖는 합금에Segregation engineering을 통하여 complexion 석출제어를 통한 마레이징 CCA의 고인성화를 달성하고자 한다. 이때, intergranular에서의 segregation 되는 원소를 찾기 위해, base system에 포함되는 elements(: Fe, Ni) 및 석출 강화 효과를 위해 첨가되는 elements(: Co, Mo)와 segregation enthalpy가 양의 관계를 갖는 element를 찾고자 하였다. 결과적으로 Mn 원소가 첨가되는 다른 원소에 대해 양의 segregation enthalpy를 갖는 것을 확인하였다. 또한 Mn 원소는 Fe 기반 합금에 첨가되었을 때 FCC 상의 안정성을 크게 증가시킨다고 알려져 있어Mn원소를 segregation engineering의 최적 원소로 선정하였다. 이 합금 설계 전략을 통해 intergranular에 FCC 오스테나이트(Υ) 상이 석출된 합금을 설계할 수 있었다. 그러나 연성 FCC Υ 상이 석출에 의해 발상하는 강도-연신 trade-off를 극복하기 위해, 열역학적 계산을 통해 석출된 FCC Υ 상의 안정성이 낮은 합금을 선정함에 따라 변형 중 마르텐사이트 변태가 발생하는 변형 기구 (TRIP)를 갖는 합금을 설계하였다. 이 연구는 열역학적 계산, segregation enthalpy 계산 및 FCC, BCC, HCP 상의 상대적 안정성을 비교하는 것과 같이 비교적 간단한 요인을 사용하여 TRIP-마레이징 강을 설계하기 위한 새로운 방법을 제시하였다. 또한 상기 전략에 따라 설계된 TRIP 마레이징 강의 J-based 균열 저항 곡선 및 비선형 탄성 파괴 역학 분석 방법을 통해 균열 성장 과정에서 elastic 및 plastic 기여에 대해 고찰하였다.

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전기화학적 수소 장입에 따른 타이타늄 합금의 미세조직 및 기계적 물성 변화 연구

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Effect of hydrogen charging on microstructure and mechanical properties of Ti alloy

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ABSTRACT

In this work, hydrogen is introduced into deformed Ti alloys via cathodic electrolysis under various charging conditions, and the microstructures and mechanical properties of the specimens are examined. The presence of hydrides is verified using X-ray diffraction, scanning electron microscopy, and electron backscatter diffraction analysis based on a rescanning approach using local pattern averaging. Vickers hardness tests are then performed to assess the extent of hydrogen penetration in the Ti alloys. Compression tests are conducted to further understand the impacts of hydrides on the mechanical reliability of hydrogen-charged Ti alloys. To reinforce the experimental findings, numerical simulations are conducted utilizing experimental data to comprehend hydrogen diffusion in the Ti alloys. Subsequently, the hydrogen diffusion mechanism in the hydrogen-charged specimens is verified through the obtained results.

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대전차 무기체계용 구리라이너의 관통 성능

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Penetration Performance of Copper Liner for Anti-tank Weapon System

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ABSTRACT

'22년 2월부터 현재도 진행 중인 러-우 전쟁에서 탱크와 장갑차를 무력화시키는 대전차 미사일(ex. 재블린)이 주목받고 있다. 이러한 대전차 무기체계의 탄두는 그림1과 같이 먼로-노이만 효과에 기반한 성형작약탄두(Shaped charge)로 구성되는데, 관통 성능을 극대화하기 위해 성형작약탄용 금속 라이너로 고온/고압에서 제트 형성능 및 연신율이 우수한 구리 소재가 많이 활용되고 있다.

성형작약탄 라이너의 관통 성능 평가 방안으로는 동적인장압출 시험(Dynamic Tensile Extrusion, DTE)이 있다. DTE 시험은 원뿔 형태의 다이에 구형상의 라이너 시편을 수백 m/s로 발사하여 소재의 동적인장압출 특성을 평가하는 방법이다. 입구보다 출구 직경이 더 작은 원뿔형 다이를 통과하면서, 구형 시편은 높은 변형률 및 변형률 속도(~10^6 /s)의 고온 동적인장압출 거동을 거치게 된다. 이러한 고온/고압 영역에서의 동적인장압출 거동은 성형작약탄 금속 라이너 제트(Jet)가 생성되어 연신될 때의 온도 및 압력 범위와 유사하여, DTE 시험을 통해 금속 라이너 소재의 제트 연신율 및 형성능을 평가할 수 있다.

본 연구에서는 성형작약탄용 구리라이너의 결정립 크기에 따른 동적인장압출(DTE) 거동 및 관통 특성을 분석하였다. 본 연구그룹에서 보유, 활용 중인 진공 개스건(Gas Gun) 장비를 활용하여 DTE 시험을 수행하였으며(그림2), 시험 후 라이너 파편을 회수하여 DTE 연신율을 평가하고, 미세구조 및 경도 변화를 관찰하였다. 또한, 구리라이너 소재의 실재 고압물성모델을 활용하여 Hydrodynamics 기반 전산해석 수행하였으며, 최종적으로 성형작약탄두 관통 시험을 통해 구리라이너의 DTE 연신율과 관통 특성과의 상관관계를

고찰해보았다. 그리고 지난 십여 년간 국방과학연구소 고압충격 연구실험실과 한밭대학교 Engineered Structural Materials Design Lab에서 공동 수행한 “고압/고율 변형특성 향상을 위한 탄두소재의 나노결정립화 연구” 성과를 소개할 예정이다.

Keywords: Anti-tank Weapon System, Shaped Charge, Cu Liner, Dynamic Tensile Extrusion, Microstructure, Penetration

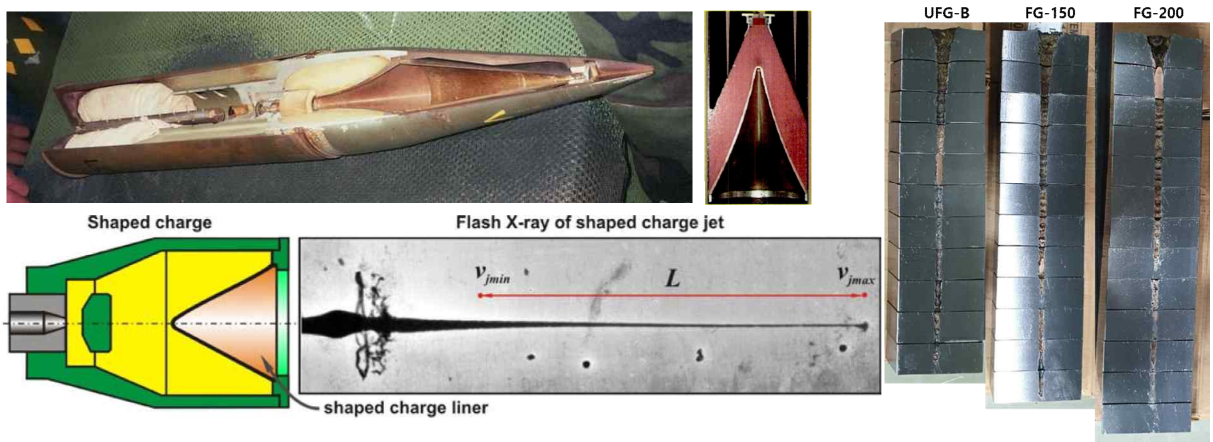

Fig. 1. Shaped Charges [1] and Penetration Test Results

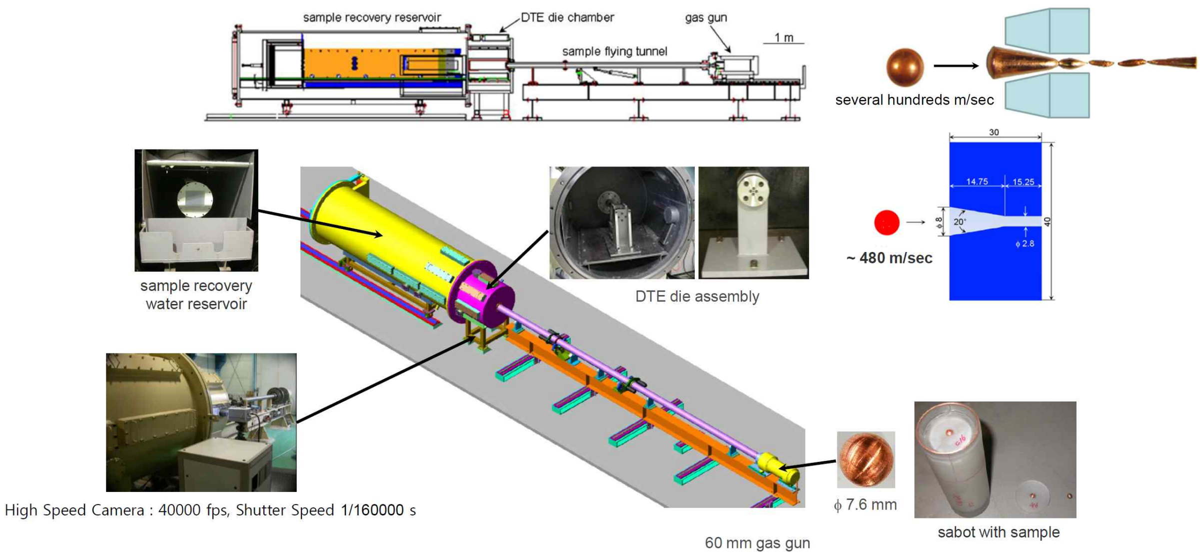

Fig. 2. Dynamic Tensile Extrusion (DTE) [2] Facility

Reference

1. W.P. Walters, J.A. Zukas, Fundamentals of Shaped Charges, 1989
2. Gray III et al., Shock Compression of Condense Matter, Americ. Inst. of Phys. (2006) 725
3. K.-T. Park et al. Materials Science & Engineering A 569 (2013) 61 - 70
4. K. Lee et al. Journal of Materials Research and Technology 9(5) (2020) 10746 - 10757

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이차전지 배터리 파우치 제작을 위한 8079 알루미늄 - cast polypropylene 분자접합 기술 개발

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Molecular Bonding Technique between 8079 Aluminum and Cast Polypropylene for Aluminum Pouches in Secondary Batteries

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ABSTRACT

The unique properties of aluminum and polymers make them indispensable for a wide range of applications. These materials offer ample opportunities for creating advanced composites that capitalize on their individual strengths. Integrating polymers with metals addresses the challenge of material compatibility, leveraging the distinct advantages of both.

Recently, aluminum laminate films have emerged as preferred packaging materials for pouch-type secondary batteries, comprising aluminum and various polymers bonded together with adhesives. However, adhesive-based bonding often results in a thick layer that can deteriorate over time, leading to decreased bonding strength and susceptibility to external impacts.

Our research focuses on a novel method for directly bonding cast polypropylene

(CPP) to 8079 aluminum alloy after surface modification, entirely bypassing the need for adhesives. Pre-treatment of the aluminum surface involved degreasing, alkali, and acid treatments. Through a systematic experimental approach, aluminum substrates were subjected to anodization in H_3PO_4 solution to introduce varying thicknesses of Al_2O_3 layers, facilitating subsequent bonding with CPP. As the oxide film thickness increased, so did the pore diameter within it. Optimal bonding strength of 21 MPa was achieved with an oxide film thickness of approximately 600 nm, which endured even after a thermal shock test at -20 ℃.

Furthermore, the aluminum surface was modified post-anodization with triazine derivatives to further enhance bonding strength. Triazines, owing to their diverse chemical reactivity, show promise in establishing robust molecular-level interactions between metals and polymers. This treatment increased the bonding strength to 31 MPa. Advanced surface characterization techniques including energy-dispersive X-ray spectroscopy (EDS), scanning electron microscopy (SEM), X-ray photoelectron spectroscopy (XPS), and contact angle measurements were employed to analyze the chemical interactions and physical characteristics at the bonded interface.

By ensuring the retention of the base materials' properties, our comprehensive approach aims to enhance the physical and chemical properties of the interface, facilitating seamless integration into precision manufacturing processes. These findings hold significant potential for advancing composite materials for the next generation, promising impactful applications across various industries.

제 38 회 첨단구조재료 심포지엄
8월 30일 [금]
제 1 발표회장

- Session 3
- Session 4

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Laser Powder Bed Fusion 공정으로 제조된 고엔트로피 및 중엔트로피 합금의 고온 산화 저항성 향상 연구

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Study on Improving High-temperature Oxidation Resistance in High-Entropy and Medium-Entropy Alloys Fabricated by Laser Powder Bed Fusion

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ABSTRACT

This study focused on evaluating the oxidation resistance of high-entropy and medium-entropy alloys (HEAs and MEAs) fabricated by the Laser Powder Bed Fusion (L-PBF) process. Although HEAs and MEAs are well known for their excellent mechanical properties and high-temperature application potential, oxidation resistance remains a critical factor for their practical use. We compared L-PBF fabricated HEAs and MEAs to conventionally made alloys. For CoCrFeMnNi HEA, the precise microstructural control boosted alloy diffusivity, forming a stable anti-oxidation layer that surpassed conventional alloys. Additionally, in the case of CoCrNi MEA, the effect of carbon addition on high-temperature oxidation resistance, based on previous studies that improved mechanical properties by adding 0.25 at% and 0.75 at% carbon (referred to as 0.25C MEA and 0.75C MEA) was examined. Carbon-doped MEA dissolved within the matrix and formed in-situ precipitates during the L-PBF process, influencing high-temperature oxidation resistance. Consequently, 0.25C MEA improved oxidation resistance, whereas 0.75C MEA showed lower one. These findings suggest that L-PBF not only enhances the mechanical

properties of these advanced alloys but also provides an improving method for manufacturing oxidation-resistant materials.

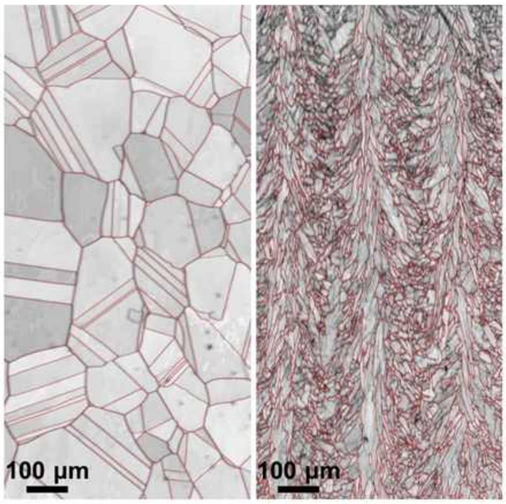

Fig. 37 EBSD band contrast maps of the conventional CoCrFeMnNi HEA and L-PBF built CoCrFeMnNi HEA

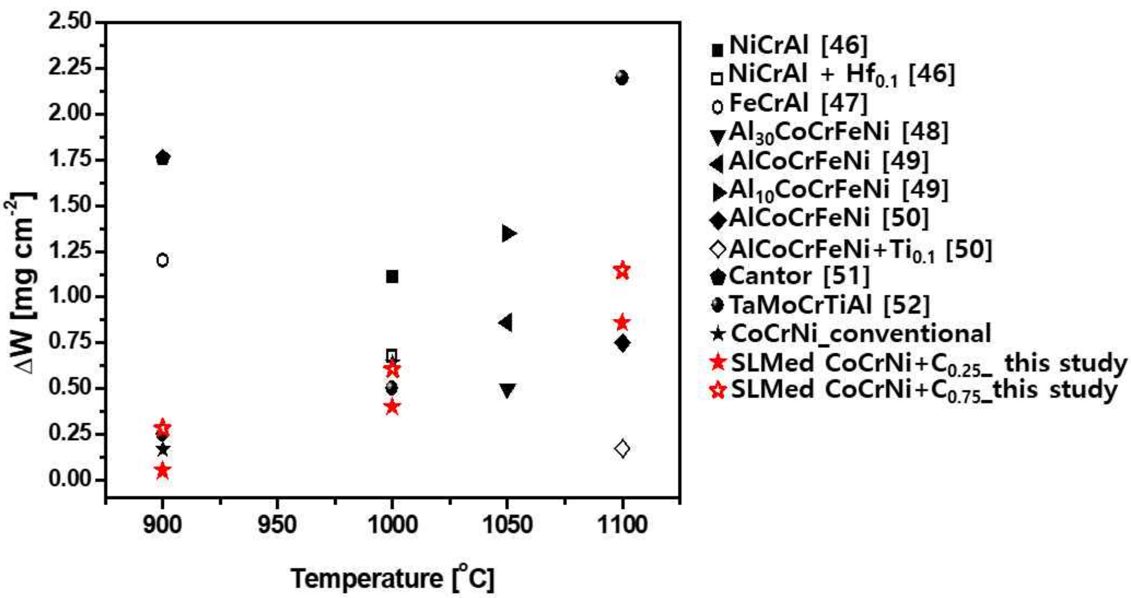

Fig. 38 Comparison of high-temperature oxidation resistance properties of HEAs and MEAs

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Laser direct energy deposition 공정으로 제조된 high-carbon tool steel의 미세조직 및 기계적 특성에 미치는 후열처리 영향

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Effect of post-heat treatment on hierarchical microstructure and mechanical properties of high-carbon tool steel manufactured via laser direct energy deposition

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ABSTRACT

Effect of post-heat treatment on the microstructure and mechanical properties of 5wt% Cr cold work tool steel material manufactured by direct energy deposition (DED) and conventional processes were investigated. As-built sample (DED-built) represented lath martensite, retained austenite matrix with carbide network and transformed to martensite with small carbides after heat treatment (DED-HT). Tensile strength increased significantly after post-heat treatment from 1340 MPa to 1949 MPa. Also, DED-HT sample showing higher impact toughness compared to the conventional sample after heat treatment (Wrought-HT). In addition, Wrought-HT showed finer martensite size and fine carbide characteristics compared to DED-HT, and many plate twinned martensite were observed. Overall, DED-HT showed excellent strengthening effect due to higher dislocation density, whereas Wrought-HT had a dominant strengthening factor due to fine grains and carbide.

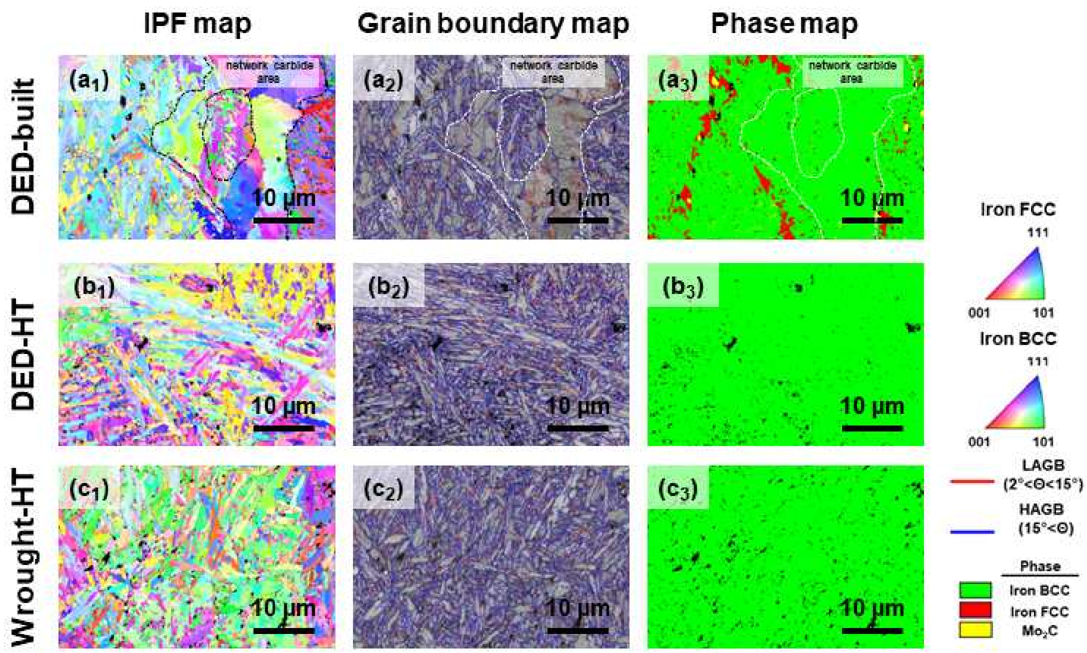

Fig. 1 EBSD analysis results of DED-built, DED-HT and Wrought-HT high-carbon tool steel with (a_1-c_1) inverse pole figure map, (a_2-c_2) grain boundary map (a_3-c_3) phae map.

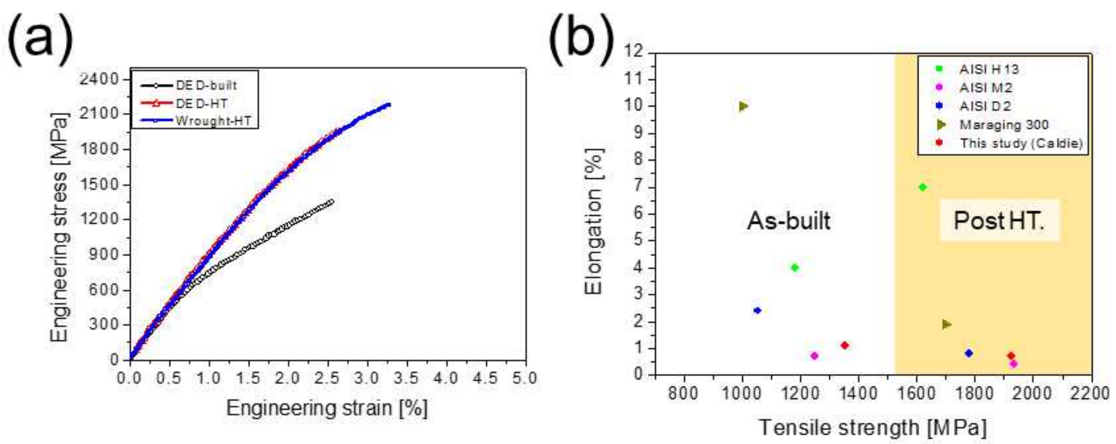

Fig. 2 Room temperature tensile properties of DED-built, DED-HT and Wrought-HT high-carbon tool steel: (a) tensile stress-atrain curve (b) tensile properties comparison with other high strength steels manufactured by direct energy deposition process.

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Fe/Al 및 Ni/Al 다재료 적층제조를 위한 계면반응분석 및 이종접합계면 형성기법

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Analysis of interfacial reaction and development of dissimilar joint interfaces for Fe/Al and Ni/Al multi-material additive manufacturing

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ABSTRACT

The joining of Fe/Al and Ni/Al dissimilar metals have been studied for its potential applications in various industrial applications for the use of synergetic effect between unique properties of Fe, Ni and Al alloys. On the other hand, additive manufacturing technology has advanced beyond creating optimized features, from strengthening materials to make them lightweight to fabricating multi-material combinations that offer functionalities beyond the capabilities of individual materials. In this study, a processing method for laser-directed energy deposition (LDED) is developed to achieve dense multi-material features, and a design that combines different and dissimilar materials is developed.

For the Fe/Al multi-material LDED, aluminum and iron has to be joined together. However, aluminum is a special metal with unique chemical and physical properties, including high reactivity to iron that hinders the multi-material additive manufacturing of aluminum and iron-based alloys. The direct deposition of the aluminum alloys onto stainless steel is impossible because the aluminum alloy sides off the base steel. Therefore, a novel anchor design of AISI 316L stainless steel was developed to prevent this detachment.

Joining Ni/Al dissimilar metals can be applied in electronic packaging and electrified

automobile since nickel has excellent thermal stability and corrosion resistance while aluminum has low density and excellent thermal dissipation behavior. For the multi-material LDED of Ni/Al, the interfacial reaction between deposited Al-10Si-1Mg and Inconel 625 substrate during L-DED process was systematically investigated. The results showed that as the volumetric energy density increases, intermetallic compounds phase becomes thicker and defects such as cracks tend to occur. When an optimized LDED condition was used, the interface exhibits reliable tensile interfacial strength, in the range of 11 – 34 MPa.

In summary, interfacial reactions between Fe/Al and Ni/Al dissimilar metals during the LDED process was investigated. Fe/Al dissimilar joint could not be directly achieved by the LDED process. In this case, a specially designed micro-anchor design could make a reliable mechanical joint. The Ni/Al dissimilar joint could be directly achived by the LDED of Al on Ni, under optimized LDED conditions.

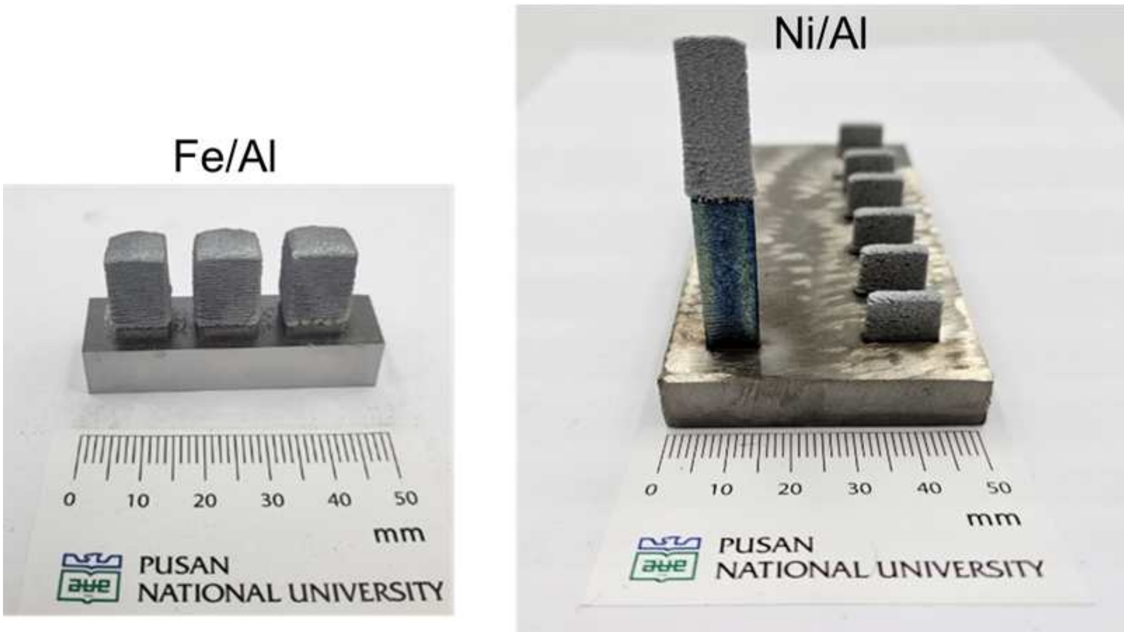

Figure 1. Fe/Al and Ni/Al dissimilar joints produced in this study.

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금속 3D 프린터 (L-PBF)로 제조된 316L/17-4 PH 스테인레스 스틸의 기계적 특성 및 미세조직적 해석

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Mechanical Properties and Microstructural Analysis of 316L/17-4 PH Stainless Steel Manufactured by Metal 3D Printer (L-PBF)

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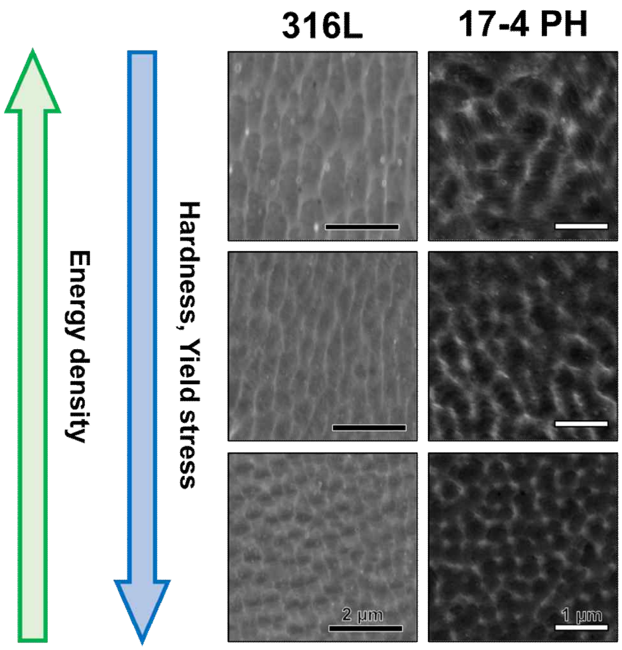
ABSTRACT

금속 적층 제조는 복잡한 형상의 맞춤형 소재 제작이 가능하고, 적층 시 국소적인 고에너지 입열로 인해 기존 제조공정 대비 다양한 미세구조가 형성된다. 특히 공정조건에 따라서 상이한 기계적 거동을 보이는 것으로 알려진 17-4PH강의 경우, 델타페라이트, 잔류오스테나이트, 마르텐사이트등의 다상구조 뿐만 아니라 전위셀 구조가 함께 형성되는 복잡한 미세구조를 갖기에, 각 상의 형성 및 전위셀 구조와 기계적 거동 사이에 대한 상관관계를 명확하게 구별하기가 쉽지 않은 상황이다. 본 연구에서는 레이저 파우더 베드 퓨전(LPBF) 공정에서 대표적인 공정변수인 에너지 밀도 변화에 따른 17-4 PH강의 기계적 특성을 파악하기 위해 경도 및 인장 실험을 진행하고 다양한 방식으로 미세구조를 관찰하여 전위셀의 밀도와 각 상의 비율이 기계적 거동에 미치는 역할을 분석하였다. 그 결과 에너지 밀도가 증가함에 따라 잔류 오스테나이트 양이 증가하고 항복이후에 TRIP(Transformation Induced Plasticity) 거동이 주요 기작으로 작용하여 높은 인장강도와 연성을 나타내는 것으로 확인되었다. 이에 반해 항복강도와 경도의 경우는 결정립내에 존재하는 전위셀 크기와 상관관계가 있다는 사실을 확인하였다. 본 연구의 결과는 17-4PH강의 적층 제조 공정을 최적화할 수 있는 방안을 제시함과 동시에 향후 다상 조직이 생성되는 합금의 적층 제조에 있어서 기초적인 가이드 라인을 제시할 수 있을 것으로 기대된다.


316L
17-4 PH
Energy density
Hardness, Yield stress
2 µm
1 µm

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L-PBF로 제조된 316L 스테인리스강의 준정적 인장 및 샤르피 충격 거동

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Quasi-static and impact behavior of 316L stainless steel manufactured by L-PBF

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ABSTRACT

Stainless steel 316L (SUS316L) produced via Laser Powder Bed Fusion (L-PBF) is renowned for its excellent combination of strength and ductility. Consequently, many recent studies have focused on the mechanical behavior of SUS316L manufactured through L-PBF. However, research on its fracture behavior, particularly concerning the ductile-brittle transition, remains sparse. Despite its outstanding mechanical properties, the transition from ductile to brittle behavior can restrict its use in various applications, especially in extreme environments like arctic ships, offshore plants, and aerospace. This study accessed the quasi-static and impact behavior of additively manufactured 316L stainless steel through a series of tensile and Charpy impact tests. Results indicated that the impact absorption energy of L-PBF SUS316L is lower than that of conventionally produced cast materials. A decrease in impact absorption energy was observed as the testing temperature decreased from room temperature (25°C) to cryogenic temperature (-196°C). Furthermore, analysis of the fractured surfaces revealed a transition from a dimpled to a cleavage fracture surface with decreasing temperature. Microstructure analyses were performed with respect to the strain rate and testing temperatures, along with quasi-static tensile tests at both

room and cryogenic temperatures, to elucidate the mechanisms underlying the temperature-dependent fracture behavior.

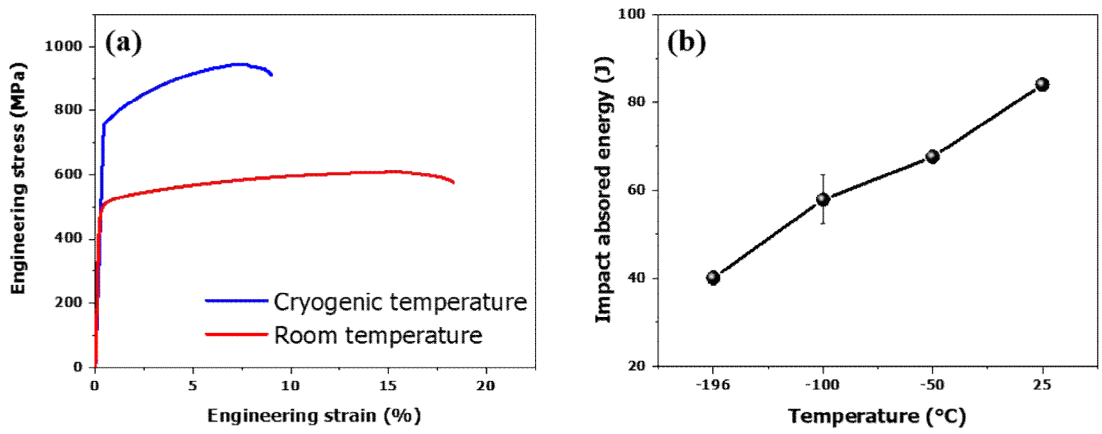

Fig. 1. (a) Quasi-static tensile stress-strain curves at room- and cryogenic-temperatures; (b) Impact absorbed energy under Charpy impact tests.

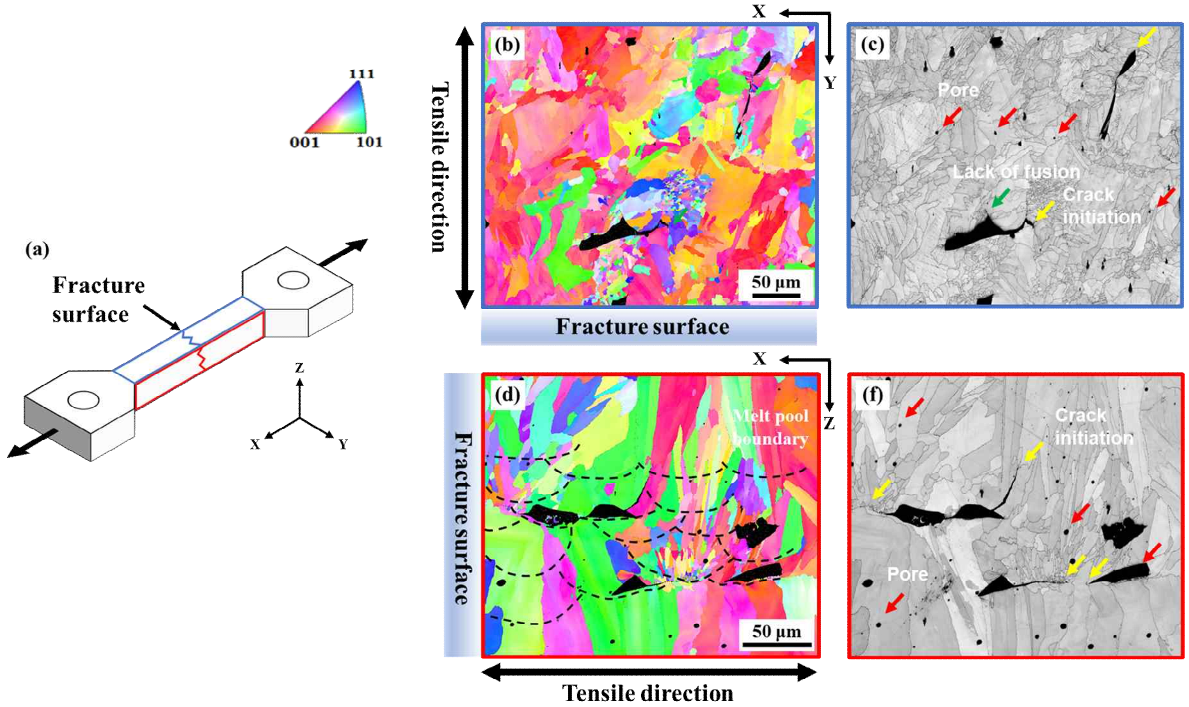

Fig. 2. (a) Schematic of tensile deformed specimen. EBSD maps showing crack initiation and propagation in the (b-c) XY and (d-f) XZ planes of the fractured specimen subjected to quasi-static tensile testing at cryogenic temperature. The red arrows indicate crack initiation, the yellow arrows point to pores, and the green arrows show areas with a lack of fusion.

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저온 분사 - 야금학적 관점에서 응용까지

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Cold Spraying - from metallurgical perspective to applications

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ABSTRACT

Cold gas dynamic spraying or kinetic spraying was first developed in the mid-1980s at the Institute of Theoretical and Applied Mechanics of the Siberian Division of the Russian Academy of Science in Novosibirsk and has emerged as a new coating technique because the process operates at low temperature and high pressure compared with conventional thermal spraying processes. In cold spraying, micron sized particles (typically 1-50 μm) are accelerated to high velocity (300-1200 m s^{-1}) by supersonic gas which is generated through a convergent-divergent de Laval nozzle, thereby making successful deposition on a substrate without any significant thermal energy injection. Subsequent impacts of particles onto a substrate or previously deposited layer can induce substrate cratering and localized plastic deformation of particles, enabling first layer build-up, metallurgical and/or mechanical bond formation and deposition of particles.

Bonding mechanism in cold spraying has been an issue as it is being considered as a key understanding for development of cold spraying technology. A prevalent opinion is that bonding of cold sprayed deposits depends on the occurrence of adiabatic shear instability (hereafter referred to as ASI) at interface, based on finite-element analysis (FEA). This phenomenological characteristic is directly related to the abnormal strain/temperature rise and stress collapse, which is attributed to severe and localized plastic deformation at the impacting interface.

Moreover, dynamic recrystallization and/or recovery are considered as main microstructural characteristics with respect to stacking fault energy (SFE) of impact materials. Basically, interface reactions and impact phenomena in cold spraying are mainly attributed to the plasticity of material. Ultra high-strain-rate severe plastic deformation (up to ~10^9 s^{-1}) by particle/substrate impact in a very short time (10^{-8}–10^{-7} s) induces localized adiabatic heating at interface, which plays a significant role in generating “adhesion” energy.

In a few cold spray coatings, near theoretical density can be obtained in the as-sprayed condition, with proper spray parameters. Also, large size and shapes (bulk forms) can be easily spray fabricated and geometrical features can be incorporated during spray preparation (using a robot system), followed by machine finished.

Besides the metallic coatings, many applications such as aerospace, automobile, biomaterials, amorphous alloys/bulk metallic glass, cermets, various composites, electronics, energy, joining, freeform fabrication, photocatalyst, polymer, sputtering target, superconducting materials, MCrAlY bond coat for thermal barrier coating, repair of damaged parts, corrosion, oxidation and wear/erosion resistant coatings have attracted significant interest in potential industries.

The production of ideal bulk nanostructured materials (NSM) is of importance and is a challenge to materials scientists from both scientific and technological points of view because NSM possess the special and advanced properties (e.g., high strength combined with good ductility, high fatigue life and superplasticity at relatively low temperature). Nanostructures, i.e., nano-sized grains (NGs) and nanoscale twins (NTs) have recently been topics of great interest from both scientific and technological points of view in the engineering of metals and alloys, as mixtures of NGs and NTs generated in bulk materials under specific deformation conditions have demonstrated novel properties, such as high strength with reasonable ductility and improved tribological properties. The issue of how the strain and temperature generated during spraying affect the nanostructuring of the metallic deposits needs to be addressed. To answer this question, the aim of this study is to investigate the correlation of particle impact conditions with microstructural refinement and nanomechanical properties in cold sprayed metals.

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적층제조에 기반한 Ni기 초내열합금의 접합 보수 시 계면부의 기계적 특성

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Mechanical property changes at the interface of partially repaired Ni-based superalloy by directed energy deposition

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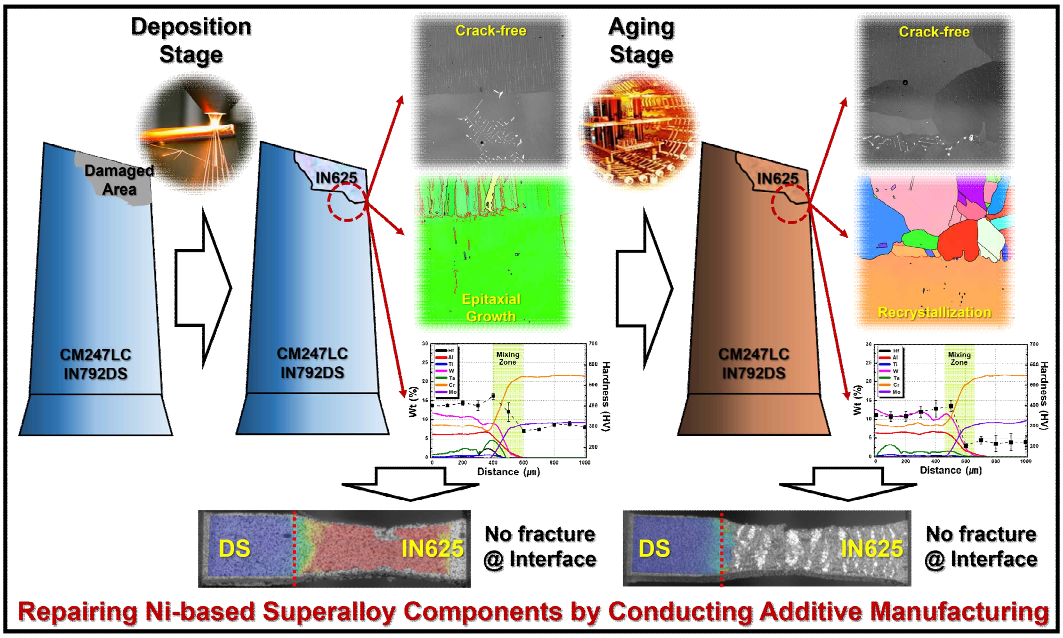
ABSTRACT



Partial repairing of damaged parts in gas turbine system is important for minimizing maintenance budgets during an operation period. Among various repairing methods, directed energy deposition (DED) method has several advantages including inert environment by shielding gas, reduced heat affected zone by high cooling rate, and high degree of freedom that might be beneficial to conduct partial repairing of Ni-based superalloy parts without hot crack initiation. To validate this strategy, in this work, mechanical property changes at the interface of partially repaired Ni-based superalloy was investigated by depositing various Inconel alloys on the directionally solidified Ni-based superalloy parts.

To minimize the external defect (e.g. pores and lack of fusion) in the deposited layer, optimal DED parameters were estimated by conducting a response surface method Based on the optimal DED processing parameters, various Inconel alloys were deposited on the directionally solidified Ni-based superalloy substrate, and the microstructural evolution near the interface was analyzed by conducting multiscale microstructural characterization techniques. For a practical application, post-heat treatment condition for deposited sample was set to be same as the commercial aging conditions for directionally solidified substrates. Because the fast-cooling rate during DED prevents the liquation cracking, microstructural characterization result represents the micro-crack fraction near the interface after DED was smaller than that of the conventional weld repairing process.

To check the mechanical reliability near the interface region, uniaxial tensile test was conducted in both vertical and horizontal direction. Because the sub-sized tensile specimen has a limitation to apply extensometer, digital image correlation method was conducted to analyze the strain distribution changes during tensile deformation. Since the strength difference between deposited layer and substrate is high, fracture was mainly induced near the deposited layer while the interface is maintained even after tensile test. Thus, the present strategy might be effective to repair Ni-based superalloy components, mechanical property degradation in the deposited layer should be minimized. Thus, additional alloy development for achieving high recrystallization temperature and strength on substrates might be required to enhance the lifetime after DED-based repairing.

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적층제조공정 활용 고내식 타이타늄 기지 복합재 개발 연구

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Enhanced Mechanical Properties and Corrosion Resistance of CP Titanium through WC Addition via Additive Manufacturing

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ABSTRACT

Commercially pure titanium (CP Ti) is highly valued in aerospace, marine, and petrochemical industries due to its exceptional corrosion resistance. This outstanding property makes CP Ti a critical material for applications exposed to harsh environments and aggressive chemicals. However, despite its advantageous corrosion resistance, CP Ti exhibits moderate strength and limited wear resistance, which constrain its broader application in situations requiring higher mechanical performance and durability. Addressing these inherent weaknesses is crucial for expanding the utility of CP Ti in more demanding applications.

To overcome these limitations, this study investigates the enhancement of CP Ti's mechanical properties and corrosion resistance through the incorporation of tungsten carbide (WC) using additive manufacturing techniques. The addition of WC is anticipated to significantly improve the mechanical properties and wear resistance of CP Ti, leveraging the hardness and reinforcement capabilities of WC. Additive manufacturing, specifically Directed Energy Deposition (DED), was employed to fabricate CP Ti-WC composites with varying WC contents (1 wt% to 5 wt%).

During the DED process, high-energy laser melting is utilized, which leads to the decomposition of WC into titanium carbide (TiC) and tungsten (W). This decomposition occurs because of the high affinity of titanium for carbon, resulting in the formation of TiC, while W is retained in solid solution within the titanium matrix. The in-situ formation of TiC particles during additive manufacturing contributes to significant microstructural refinement and the formation of a fine-grained structure.

The uniform dispersion of TiC particles throughout the matrix acts as effective barriers to dislocation movement, enhancing precipitation strengthening and improving wear resistance. Concurrently, W contributes to solid solution strengthening, further augmenting the composite's mechanical properties. The results demonstrate that the addition of WC and the subsequent formation of TiC and W lead to substantial improvements in the mechanical properties of the CP Ti-WC composites. Notably, the hardness and tensile strength values reached maximum levels of 362.2 HV and 1042 MPa, respectively, for the composite containing 5 wt% WC. These enhancements are attributed to the combined effects of microstructural refinement, solid solution strengthening from W, and precipitation strengthening from TiC particles.

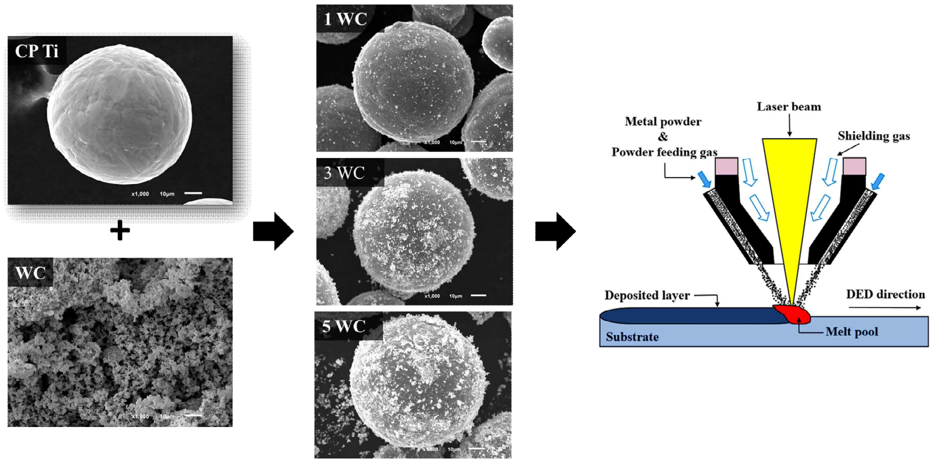

Fig. 1. Schematic illustration of the preparation process for Ti-WC powders and the subsequent additive manufacturing process.

In addition to mechanical enhancements, the study also highlights a significant improvement in the corrosion resistance of CP Ti with the inclusion of WC. Corrosion tests were conducted in a 70% H_2SO_4 solution, simulating aggressive acidic environments. The composite with 5 wt% WC exhibited the lowest mass loss and current density, indicating superior corrosion resistance compared to pure CP Ti. This improvement is attributed to the formation of a stable and protective oxide layer, facilitated by the refined microstructure and the presence of TiC particles. The TiC particles provide nucleation sites for the oxide layer, promoting its uniform formation and stability.

This research highlights the potential of CP Ti-WC composites fabricated through additive manufacturing for demanding applications requiring superior mechanical properties and corrosion resistance. The insights gained into the decomposition of WC and the resultant effects of TiC and W on the microstructure and properties of CP Ti provide valuable guidelines for optimizing the performance of titanium-based composites in various industrial applications.

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Laser-powder bed fusion 적층제조 및 전위 셀 기반 나노 카바이드 석출을 활용한 초고강도 AISI D2 공구강 개발

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Dislocation cell-mediated nanosized carbide precipitation enables superstrong AISI D2 tool steel fabricated via laser-powder bed fusion

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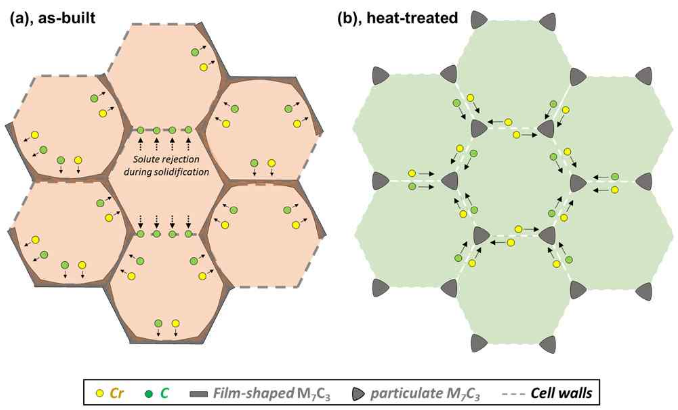
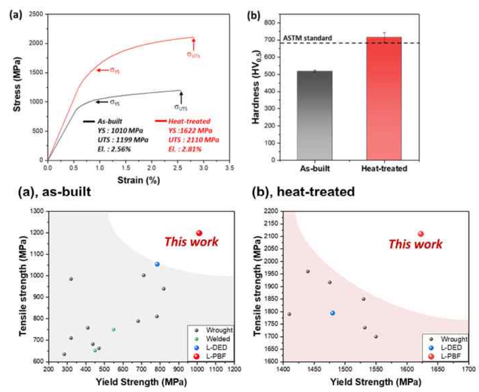
ABSTRACT

D2 tool steel is a prominent cold work tool steel used in applications such as drills, knives, and molds due to its excellent strength, hardness, and wear resistance. Although the high hardness of D2 tool steel makes it a competitive material for die and mold applications, its high hardness also imposes the difficulty of machining. In this respect, D2 tool steel has been a promising application field for laser additive manufacturing. This study aims to elucidate the influence of applying laser-powder bed fusion (L-PBF) on the microstructure and corresponding mechanical properties of D2 tool steel. Base plate preheating of 200 ºC and careful manipulation of processing parameters enabled the successful fabrication of L-PBF D2 tool steel, with a relative density of over 99.9%. The as-built D2 alloy exhibited an austenite matrix with fine cellular solidification structures and a film-like distribution of carbides formed along these structures due to L-PBF. Upon heat treatment, carbides agglomerated and spheroidized along the cell walls in the as-built state, demonstrating a nano-sized fine distribution within the martensite matrix. The L-PBF D2 tool steel showed exceptionally superior strength both in the as-built and heat-treated states compared to conventionally reported fabricated D2 tool steel without severe sacrifice of ductility. The underlying mechanisms for microstructure formation and subsequent strengthening were studied in detail. These findings imply that the dislocation cell structure-mediated precipitation successfully strengthened the D2 alloy, suggesting novel strategies for designing high-strength alloy utilizing L-PBF.





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직접 분사 증착법을 활용한 Fe-Mn-Al-C 경량철강 조성 탐색

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Composition exploration of Fe-Mn-Al-C lightweight steels via directed-energy deposition

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ABSTRACT

In response to recent global carbon neutrality policies, various industries including automotive, aerospace, and energy increase the interest in lightweight materials, and Fe-Mn-Al-C lightweight steels (LWSs) present exceptional mechanical properties and reduced density. Furthermore, with additive manufacturing (AM) emerging as an innovative manufacturing method, various metal powders are applied in additive manufacturing. Research has been conducted to develop alloy powders optimized for AM. Directed energy deposition (DED) is a technique that involves deposition of different powders into a melt pool, allowing for in-situ alloying and composition control by adjusting the powder feed rate. Thus, DED technique can be utilized for experimentally designing alloy powders for AM through combinatorial approach. In this study, we aimed to develop LWSs for AM through composition exploration using DED. Based on phase prediction through thermodynamic calculations, we selected the composition range of LWSs to be 8, 10, and 12 wt.% in Al (referred to 8Al, 10Al, and 12Al, respectively) and 15, 20, 25 wt.% in Mn (referred to LM, MM, and HM, respectively). By controlling the feed rates of each Fe-Mn-Al-C, Fe-Mn, and Fe-Al powder, we prepared a series of Fe-Mn-Al-C LWSs. And then, their microstructures and tensile properties were evaluated.

Figure 1 presents electron backscatter diffraction (EBSD)-inverse pole figure (IPF) and phase distribution maps of (a) 8Al, (b) 10Al and (c) 12Al LWSs. For 8Al and 10Al LWSs, austenite and ferrite phases are observed; 8Al LWSs reveal the austenite matrix with minor ferrite grains, while ferrite matrix and minor austenite phases are observed in 10Al. Moreover, 12Al LWSs reveal κ-carbides precipitated at grain boundaries of ferrite matrix, as shown in Fig. 1(c).

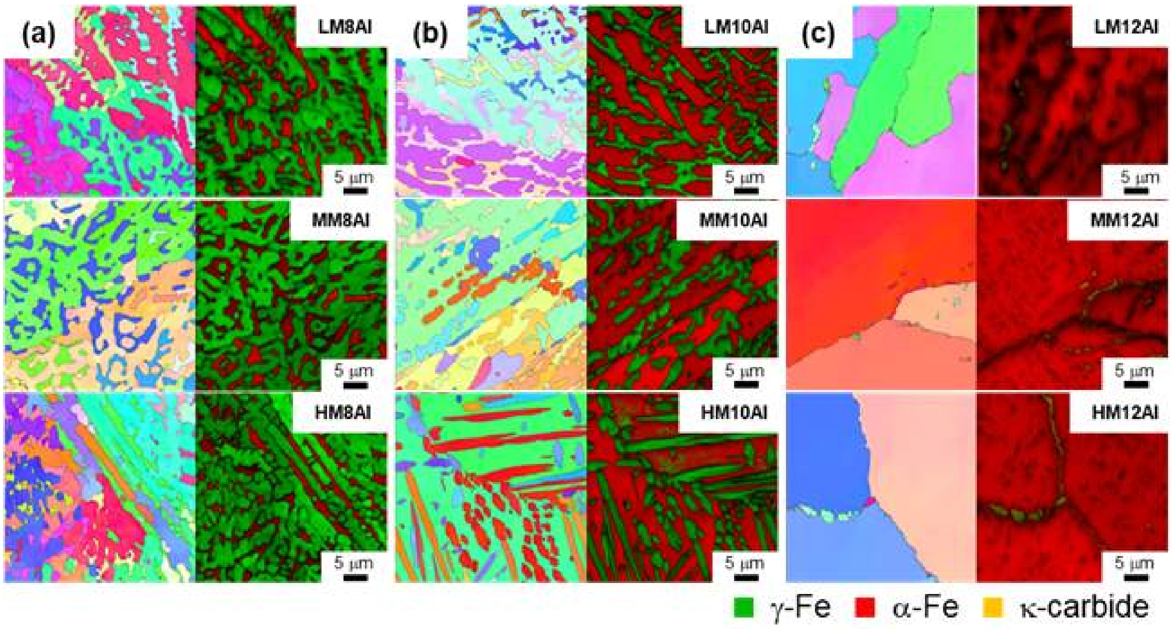

Fig. 1 EBSD-IPF and phase maps of (a) 8Al, (b) 10Al, and (c) 12Al LWSs

Figure 2 shows the tensile engineering stress-strain curves of the 8Al, 10Al and 12Al LWSs. The 8Al LWSs presented similar yield strengths of 608.6, 644.8, and 619.7 MPa and tensile strength of 851.2, 883.2, and 818.3 MPa in LM, MM, and HM, respectively. The strength of 10Al tends to decrease from 879.9 to 628.2 MPa in yield strength and from 1056.3 to 850.8 MPa in tensile strength with increasing Mn contents. For 12Al LWSs, the specimens were fractured before yielding. It might be because of the presence of the brittle B_2 phase. We will further discuss the mechanical behaviors of DED-LWSs.

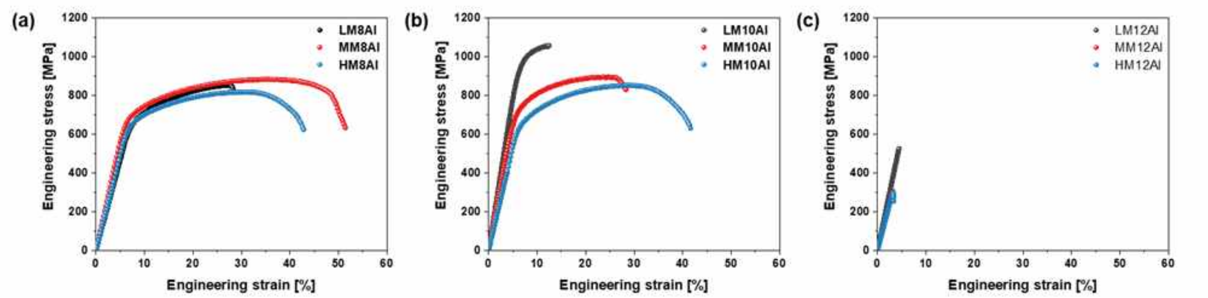

Fig. 2 Engineering strain-stress curves of (a) 8Al, (b) 10Al, and (c) 12Al LWSs

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LP-DED 방식을 이용한 기능성경사재료(FGM) 제작 및 특성 분석

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Manufacturing and Characterization of Functionally Graded Materials (FGMs) Using LP-DED technology

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ABSTRACT

Functionally Graded Materials (FGMs) are materials characterized by a gradual variation in composition, resulting in corresponding changes in physical properties. This allows for enhanced thermal resistance, mechanical strength, and other specific functional performance, making FGMs widely researched for applications in aerospace, automotive, machinery/equipment, medical, and other industries. FGMs can be produced using various manufacturing technologies ranging from traditional casting to additive manufacturing, and the appropriate manufacturing method can be selected based on the desired shape, size, and structure. Among these, the LP-DED method has the advantage of quickly producing FGMs by allowing the composition of multiple materials to be changed layer-by-layer. This paper aims to explain the characteristics and advantages of the LP-DED method for FGM production through practical examples. The LP-DED method is a type of additive manufacturing technology where metal powder is locally melted by a laser beam to create metal parts. It is categorized into coaxial systems, where the metal powder and laser beam are emitted from the same axis, and non-coaxial systems from different axes. Generally, coaxial systems are used, where the module emitting the metal powder and laser beam is mounted on a CNC or robot system to layer the material and create parts. Unlike other additive manufacturing methods, the LP-DED method directly injects metal powder for layering, allowing multiple types of metal powders to be used simultaneously or layer-by-layer. This advantage makes it actively applied in

multi-material research, such as FGMs, and allows quick and convenient production of FGM test pieces or parts by changing the ratio and combination of multi-materials in-situ without pre-mixing. This paper introduces three FGM case studies produced using InssTek's MX-Lab LP-DED 3D printer. Table. 1. shows the materials, gradient steps, and gradient directions used in the production of the three FGM test pieces. The three FGMs produced using LP-DED technology were analyzed to determine if the composition of the two materials varied linearly through EDS mapping, and the results are shown in Fig. 1.

Table. 3. Test materials & Conditions

No.	Material 1 (UNS code)	Material 2 (UNS code)	Gradient Step	Gradient Direction
1	S31600	C95300	22	Z
2	S31600	C95300	50	XY
3	R04295	R56400	11	Z

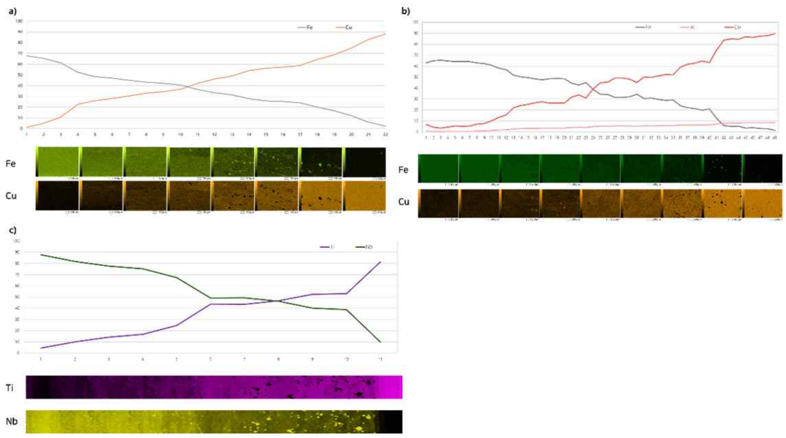

Fig. 1. EDS mapping [a) No.1 Test, b) No. Test, c) No.3 Test]

Based on the results of the three test pieces, it was confirmed that FGMs with stepwise linear composition changes could be successfully produced using the LP-DED method. However, incomplete melting and cracking were observed in some test pieces, attributed to differences in melting temperatures and laser energy absorption rates between the two materials. Additionally, residual stress caused by different thermal expansion coefficients after rapid cooling from high-temperature laser melting was identified as a cause of cracking. To address these issues, optimizing process parameters for each composition is essential, and excluding certain compositions may be considered if necessary.

In this paper, the methodological aspects of producing FGMs using the LP-DED method and the macroscopic evaluation of the produced FGMs were reviewed. It was confirmed that this method is faster and more convenient for realizing FGMs than traditional manufacturing methods and PBF techniques that use pre-mixed materials. Continuous research on FGM production using LP-DED technology is ongoing, with future plans to study process optimization and microscopic behavior for each ratio.

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- Session 3
- Session 4

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Sc 미량 첨가를 통한 마그네슘 소재 내부식성 향상

김정기, 민두원, 권재호, 박성수
울산과학기술원 신소재공학과

Upgrading the corrosion resistance of Mg alloy by Sc microalloying

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ABSTRACT

Mg alloys are considered one of the most attractive structural materials for mobile goods such as personal vehicles and portable devices. However, industrially using Mg-based products in a variety of weight-sensitive components is still limited especially due to their poor corrosion resistance. It has been reported that the poor corrosion resistance is closely related with the occurrence of active microgalvanic corrosion between the Mg matrix and second-phase particles.

Here, we report that microalloying with Sc is highly effective in upgrading the corrosion resistance of Al-containing Mg alloy. Weight-loss-based corrosion rates evaluated after immersion in 0.6 M NaCl solution for 72 hours were 0.38 and 22.2 mm y^{-1} for the Mg-3wt.% Al alloys with and without 0.05wt% Sc microalloying, respectively. The excellent corrosion resistance appearing in the experimental Mg alloy with Sc is attributable to the reduced electrochemical nobility of cathodic second-phase particles after controlled microalloying, resulting in significantly retarded microgalvanic corrosion in the corrosive condition. The beneficial effect of alloyed Sc in the Mg alloy is discussed in consideration of Sc-induced microstructural modifications.

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부식저항형 마그네슘 신 합금의 생체분해 특성

민두원, 김정기, 권재호, 박성수
울산과학기술원 신소재공학과

Biodegradation behavior of novel corrosion-resistant Mg alloy

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ABSTRACT

Of various metallic elements, Mg is considered one of the most feasible biodegradable materials since it can be excreted in the urine after degradation in the body. However, commercially available Mg and its alloys generally suffer from more rapid and localized degradation than other biodegradable materials in an aqueous environment containing salts like seawater or blood, resulting in their premature decay after implantation. Furthermore, H_2 gas bubbles generating during rapid degradation of Mg can cause inflammation by creating cavities on the tissue. Here, as an alternative to the conventionally available Mg-based materials, the authors suggest a new type of Mg alloy with highly enhanced corrosion resistance, giving expectations to exclude the active biodegradation after its implantation. In this study, the biodegradation behavior and biocompatibility of the experimental and commercial Mg alloys were comparatively investigated to see the possibility of the new material in future biodegradable implant applications.

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질화자가소결공정을 활용한 알루미늄 복합소재 개발

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Development of Nitridation-Induced Self-Formed Aluminum Matrix Composites

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ABSTRACT

We developed a simple and innovative process for the manufacture of aluminum matrix composites (AMCs). In this nitridation-induced self-formed aluminum composite (NISFAC) process, aluminum powder and ceramic reinforcement mixtures are heated in nitrogen gas, allowing the exothermic nitridation reaction to partially melt the aluminum powder to assist composite densification and improve the wetting between aluminum and ceramic. The formation of a sufficient amount of molten aluminum is key to producing sound, pore-free AMCs; hence, the degree of nitridation is a key factor. This can be controlled by the chemical composition and particle size of the aluminum powder, the type, size, and volume fraction of the ceramic reinforcement, and processing variables such as temperature, time, and the flow-rate of nitrogen gas. We also examined the effect of reinforcement volume fraction, particle size and processing temperatures upon the nitridation behavior. It is demonstrated that the nitridation behavior is not affected by these variables acting independently; therefore, a systematic study is needed in order to examine the concerted effect of these variables so as to determine the optimal conditions to produce AMCs with desirable properties for target applications.

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타이타늄의 고상동소변태에 미치는 전류의 비열적 효과 연구

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Study on the athermal effect of electric current on solid-solid phase transformation of titanium

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ABSTRACT

This study delves into the intriguing influence of electric current on the solid-solid phase transformation behavior of titanium. The research focuses on elucidating the impact of electric current on the α/β phase transition temperatures in pure titanium samples. We employ a comprehensive approach, combining ex-situ and in-situ methodologies specifically designed for precise measurement of phase transition points under the influence of both heat treatment and electric current.

The current effect is a combination of the thermal effect resulting from Joule heating and the athermal effect. There has been much controversy about the origin of the athermal effect, but there is no disagreement that it is a type of interaction between defects and electric current[1-3]. Recently, Kim et al.[4] proved computationally and experimentally that the elastic modulus changes due to charge imbalance near defect, and Jeong et al.[5] showed that the kinetic enhancement of the current effect was proportional to the square root of the current density.

Our findings reveal a remarkable phenomenon: electric current demonstrably reduces the onset temperature of the phase transformation compared to conventional heat treatment alone. To gain a deeper understanding of this phenomenon, we conducted a

series of experiments under varying electrical and microstructural conditions. This systematic exploration allowed us to establish an empirical correlation between current density, grain size, and the observed shift in the phase transformation temperature.

Building upon this empirical relation, we ventured further to quantify the athermal effect of the electric current. This quantification was achieved by employing advanced thermodynamic software, which enabled us to estimate the additional Gibbs free energy associated with the current-induced transformation. These results provide compelling evidence that the athermal effect of electric current likely originates from its interaction with inherent defects within the titanium lattice.

The implications of this research are far-reaching. By elucidating the mechanism behind the athermal effect, we contribute valuable insights that can be harnessed to refine and optimize numerous electric current-assisted processes in metallurgy. This newfound knowledge has the potential to revolutionize the field by enabling more precise control over microstructural evolution during various electric current-driven transformations in metallic materials.

References

[1] Conrad et al., "Effect of electric current pulses on the recrystallization kinetics of copper." Scripta metallurgica 22.2 (1988): 235-238

[2] Rudolf, C., Goswami, R., Kang, W., & Thomas, J. (2021). Effects of electric current on the plastic deformation behavior of pure copper, iron, and titanium. Acta Materialia, 209, 116776.

[3] Zhao, S., Zhang, R., Chong, Y., Li, X., Abu-Odeh, A., Rothchild, E., & Minor, A. M. (2021). Defect reconfiguration in a Ti–Al alloy via electroplasticity. Nature Materials, 20(4), 468-472.

[4] Kim, M. J., Yoon, S., Park, S., Jeong, H. J., Park, J. W., Kim, K., ... & Han, H. N. (2020). Elucidating the origin of electroplasticity in metallic materials. Applied Materials Today, 21, 100874.

[5] Jeong, K., Jin, S. W., Kang, S. G., Park, J. W., Jeong, H. J., Hong, S. T., ... & Han, H. N. (2022). Athermally enhanced recrystallization kinetics of ultra-low carbon steel via electric current treatment.Acta Materialia,232, 117925.

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전계증발 이온현미경 활용 알루미늄 소재 구조/조성 분석

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Chemical and micro-structural analysis of aluminum alloys using field evaporation microscopy

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ABSTRACT

Atom probe tomography (APT) is a powerful microscopy technique that offers atomic-scale, three-dimensional insights into materials. In this presentation, the atom probe technique will be introduced, mainly focusing on the investigation of aluminum alloys. Key findings include the identification of composition-structure-property relationships, with a focus on solutes and precipitates/clusters. It will also highlight APT's unique ability to elucidate structural details non-observable by other analytical methods, which may raise questions about composition discrepancies. Recent advancements and characterization of aluminum alloys will also be discussed in terms of APT, emphasizing the importance of APT in developing new alloy compositions and improving existing ones.

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열전지의 충격 내성 평가를 위한 대형 가스건 시험 및 시뮬레이션 기법

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Large-scale gas-gun test and its simulation for evaluating impact resistance of thermal battery

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ABSTRACT

Various electronic devices enhance the range and accuracy of missiles, rockets, and aerial shells in modern warfare. Activating thermal batteries just before launch is crucial for ensuring the operation of such equipment during high-altitude and long-range flights. Additionally, in situations where projectiles are rapidly accelerated and subjected to dynamic compression loads during firing, it is imperative for electronic equipment and thermal batteries to continue functioning without damage, ensuring reliability in war environments. Methods for evaluating the impact resistance of electronic equipment include gas gun tests and impact test platforms. Gas gun tests provide critical information on how electronic equipment operates in war by accelerating projectiles to high speeds for target collision. This method is suitable for

evaluating impact resistance as it simulates impacts similar to actual launches. Impact test platforms expose electronic equipment to various impact and vibration conditions. Other methods involve mounting equipment on simulated projectiles or impact testing devices to expose them to impacts and vibrations, similar to gas gun tests, aiding in evaluating impact resistance and obtaining reliable data.

In gas gun tests, the projectile is accelerated using high-pressure N2 gas before colliding with a lead (Pb) target, generating significant impact. The projectile is then retrieved to evaluate its resistance performance. These tests use maximum deceleration as the main evaluation criterion. While impacts are applied in the opposite direction of actual launches, they provide nearly identical deceleration values for reliable evaluations. Impact deceleration varies with factors such as shape, weight, and speed, necessitating appropriate test conditions. Projectiles are equipped with measurement devices to record acceleration changes over time, providing actual impact data.

This study aimed to measure the acceleration applied to devices like electronic equipment and thermal batteries inside projectiles, protecting them from launch impact. Additionally, it proposed methods for simulation using finite element method (FEM) analysis. Collision experiments were conducted under the assumption that these devices were mounted on the projectile. The acceleration inside the projectile was measured using an impact measuring device similar to electronic equipment. This experimental method reduced risk and cost compared to actual projectile launches. Validated FEM simulations can save time and costs, allowing for optimization of the design of projectiles and electronic equipment to enhance impact resistance.

Simulation results showed changes in velocity and head angle affected maximum deceleration and penetration depth. Decreasing the head angle was effective in reducing maximum deceleration. Comparisons between experimental and simulation results confirmed good agreement, particularly in maximum deceleration and target collision depth. As the head angle increased, maximum deceleration increased, while penetration depth decreased. Comparing peak deceleration curves for four conditions from gas gun tests and simulations revealed similar trends, indicating consistent and reliable evaluations. This study provides important information for evaluating the impact resistance of electronic equipment and demonstrates that combining experiments with simulations yields reliable results.

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초고속 가속 및 회전 환경에서 열전지의 충격 내성을 분석하기 위한 가스건 시험 시뮬레이션

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Simulations of gas-gun tests for analyzing impact resistance of thermal battery under extremely high-speed acceleration and rotation environments

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ABSTRACT

In modern warfare, electronic equipment is essential to enhance the range and accuracy of missiles, rockets, and airborne projectiles. Thermal batteries, which supply power to these systems, remain inactive until just before launch when they are activated to initiate operation. For high-altitude and long-range flights, sufficient operation time is crucial. During the launch of projectiles from cannons or launchers, involving rapid acceleration and rotation, electronic equipment and thermal batteries must continue to function without damage.

A primary method for evaluating the impact resistance of electronic equipment or thermal batteries is gas gun testing. In gas gun tests, projectiles are placed inside a gun barrel and accelerated using high-pressure gas before colliding with a lead (Pb) target, resulting in significant deceleration. Although this test applies impact in the

opposite direction of actual artillery firing, it provides nearly identical deceleration values, enabling reliable evaluations. The maximum deceleration reached during the test is the primary evaluation criterion.

Despite offering real-time impact data, performing repetitive gas-gun tests entails considerable time and cost. In actual artillery firing, projectiles rotate rapidly due to rifling spins inside the cannon barrel. Projectiles rotate further upon air contact, stabilizing their motion, reducing twisting and vibrations, and enhancing accuracy. However, simultaneously accelerating and rotating projectiles using gas guns presents challenges. Addressing this requires a structural analysis method capable of considering both acceleration and rotation in gas gun testing. This allows for simulating impacts and loads similar to gas gun tests, including rotations.

This study aimed to develop structural analysis capable of incorporating both acceleration and rotation in gas gun testing. The impact deceleration experienced by projectiles is influenced by design, flight velocity, rotation speed, and target properties. Thus, the dynamic behavior of projectiles during collisions was modeled through simulations, predicting various impact conditions. Gas gun simulation conditions and analyses were validated by comparing actual gas gun test results. Various rotation conditions were introduced to simulations to measure the impact deceleration of projectiles experiencing both acceleration and rotation, exploring methods to enhance impact resistance performance in actual artillery firing.

Projectiles equipped with impact measurement devices were rapidly launched using a gas gun and collided with a Pb target. At collision velocities of 93 or 145 m/s, the target penetration depths and maximum decelerations were 95 mm and 13,332 G, or 150 mm and 25,036 G, respectively. These results closely matched deceleration curves, maximum decelerations, and penetration depths from 2D and 3D simulations. Simulating high-speed rotating projectiles colliding with targets analyzed the influence of rotation speed on maximum deceleration and penetration depth. These analysis results were consistent with gas gun tests, providing guidelines for evaluating and improving projectile impact resistance. Simulations proved valuable for efficiently evaluating projectile impact resistance, complementing gas gun tests.

FEM simulation structural analysis revealed that while maximum deceleration slightly increased with projectile rotation speed, this difference was not significant compared to collisions without rotation. Most deformation during collisions was determined by the projectile's vibration and motion direction, with rotation having an insignificant effect while maintaining stability and efficient energy transfer. Rotational deceleration from 3D simulations increased with projectile velocity and rotation speed. Specifically, maximum rotational deceleration at 20,000 rpm was approximately 40% higher than at 4,000 rpm. Solid-state electronic equipment was hardly affected by centrifugal forces, but the stability and operational performance of thermal batteries composed of stacked unit cells and electrolytes required solid-state electrolytes to prevent liquid leakage.

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PBF Ti-6Al-4V 판재의 고주기피로 특성 평가

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High Cycle Fatigue Characteristics of PBF Ti-6Al-4V Sheet

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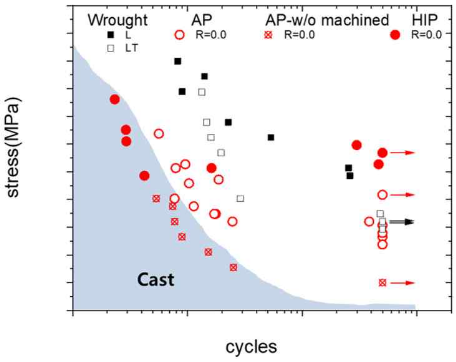
ABSTRACT

In this study, the high cycle fatigue characteristics of Ti-6Al-4V alloy plates manufactured using the Powder Bed Fusion (PBF) method were evaluated. 3D printing technologies, including PBF, are effective for improving material utilization and are anticipated to find applications in the aviation industry. The investigation focused on specimens produced by the PBF process, examining how variables such as stacking direction, post-treatment, and surface roughness affect high cycle fatigue characteristics. It was observed that these fatigue characteristics are influenced by both stacking direction and surface roughness. Based on these findings, additional technologies and measures required for the application of PBF materials in aircraft were considered.



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박판주조공법으로 제조된 알루미늄 판재의 미세조직과 기계적 특성간의 상관관계

조용희[1*], 황효진[1], 이동윤[1], 김원경[1], 어광준[1], 이윤수[1], 김형욱[1]
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Correlation betrwwen Microstructure and Mechanical properties of Aluminum strip fabricated by Twin roll casting

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ABSTRACT (11 point, Bold, Center alignment)

알루미늄 합금은 연비 향상과 탄소 배출가스 감소를 위한 경량 차량에 대한 수요가 증가함에 따라서 그 사용량이 증가하고 있습니다. 특히나 6xxx계와 7xxx계 알루미늄 합금은 대표적인 알루미늄 합금 판재 소재로써, 높은 비강도를 지니며 준수한 성형성 및 내식성 덕분에 자동차 패널 및 항공기 기체용 소재로써 사용이 됩니다. 이러한 합금은 산업적으로 Direct Chill (DC) casting 방식을 활용하여 제조된 슬라브를 기반으로 균질화, 압연 공정, 용체화 처리 및 인공시효 처리 등을 거쳐 판재로 제조됩니다. 기존의 일반적인 공정은 DC casting 방식으로 제조된 슬라브의 전처리, 균질화 공정 및 열간압연 공정을 거쳐서 열연재가 생산되기 때문에 공정이 복잡하고 시간 소모가 크며 장비 구축에 따른 비용이 많이 듭니다. 하지만 Twin Roll Casting (TRC) 공법은 용융 금속에서 바로 판재를 생산할 수 있기에 앞선 공정을 생략할 수 있어 경제적인 이점이 있습니다 (그림 1). 본 연구에서는 Horizontal-TRC (HTRC)으로 제조된 7xxx계 알루미늄 합금 판재를 통해 박판주조시 발생할 수 있는 중심부 편석대의 영향에 대해서 고찰하려고 합니다. 또한, 최근에는 고속으로 판재를 생산할 수 있도록 Vertical-TRC (VTRC) 장비가 고안되었습니다. 기존의 HTRC 장비는 통상적으로 1m/min 이하의 속도로 판재를 생산할 수 있지만, 새롭게 고안된 VTRC 장비는 20m/min 이상의 속도로 판재를 생산할 수 있습니다 (그림 2). 하지만, 아쉽게도 HTRC와 VTRC 2가지 공법으로 제조된 알루미늄 합금 판재에 대한 비교 분석을 진행한 문헌이 거의 보고가 되어있지 않습니다. 따라서 HTRC와 VTRC

2가지 공법으로 제조된 6xxx계 알루미늄 합금 판재에 대한 비교 분석을 통해, 두 가지 공법의 차이에 따른 미세조직 및 기계적 특성간의 상관관계를 해석하려고 합니다. 해당 연구는 박판주조공법으로 제조된 알루미늄 합금 판재의 독특한 미세조직학적 특성에 대한 연구 및 기계적 특성간의 상관관계를 정립함으로써, 미래모빌리티용 경량 판재 소재의 공정 개발에 기여할 수 있습니다.

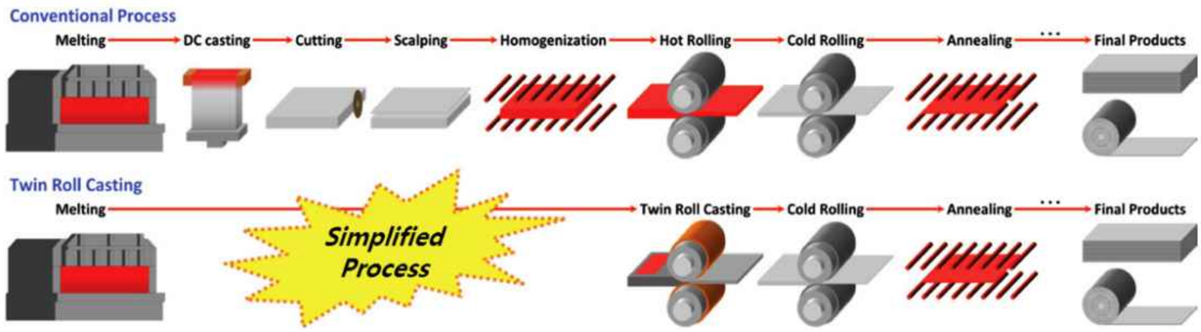

그림1. 알루미늄 합금 판재 제조를 위한 기존 공법와 박판주조공법의 개략도

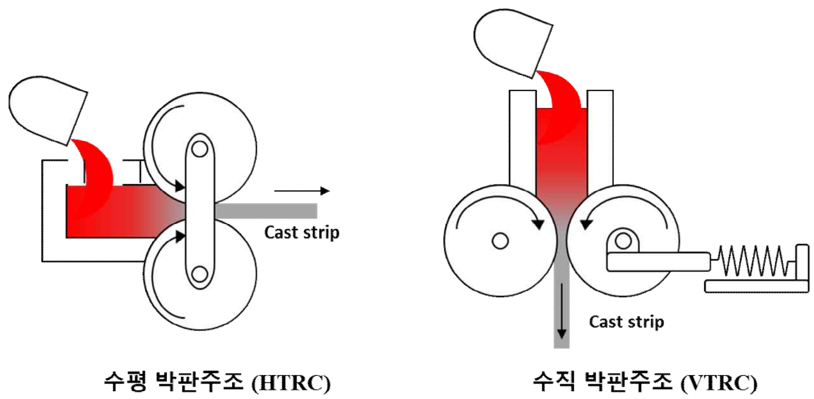

그림2. 수평 박판주조(HTRC)와 수직 박판주조 (VTRC) 장비 모식도

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제 1원리 계산 기반 합금설계를 통한 Al-Zn 합금의 강도와 연성향상

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Improvement of strength and ductility of Al-Zn alloys by alloy design based on first-principles calculations

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Extreme Materials Research institute, Korea Institute of Materials Science, Gyeongnam, Korea

ABSTRACT

Improving the mechanical properties of non-ferrous alloys using density functional theory (DFT) calculations is a new approach being implemented in the metallurgical field, and its usefulness has not yet been fully verified. However, we have demonstrated its effectiveness in the aluminum-zinc alloy system. To achieve high strength in precipitation-strengthened alloys, we investigated the interface energy between the precipitate and matrix based on DFT calculations using the VASP code[1]. In Al-Zn alloys, the coercive energy of Zn in the alloy was drastically increased, and the interface energy between the Zn precipitate and the Al matrix was modified with the addition of Cu and Mg elements, as shown in Figures 1 and 2.

The DFT results show that Cu and Mg atoms prefer to reside near the interface between the Al matrix and the Zn precipitate, reducing both the strain and the interface energy, as shown in Figure 2. Thus, we can expect that Cu and Mg ions will reduce the size of the precipitates and lead to a uniform distribution of Zn particles in the Al matrix, resulting in improved tensile strength according to the precipitation hardening theory, as shown in Figure 3. We developed cast Al-Zn alloys with high strength and ductility using Cu and Mg elements, which were selected based on the DFT calculation results. Furthermore, we confirmed that these calculation results are in good agreement with the experimental results [2].

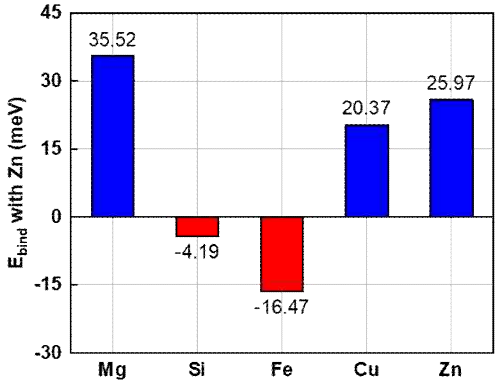

Figure 1. Cohercive energy variation of Zn phase with addition of elements

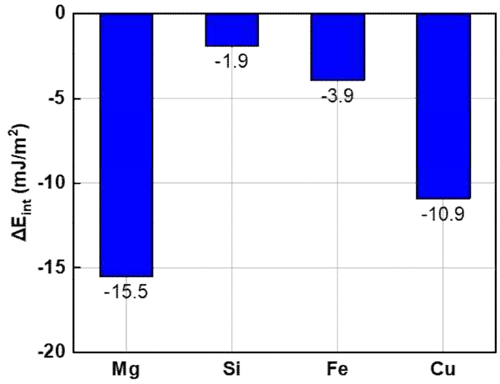

Figure 2. Interface energy variation of Zn and Al matrix with addition of elements

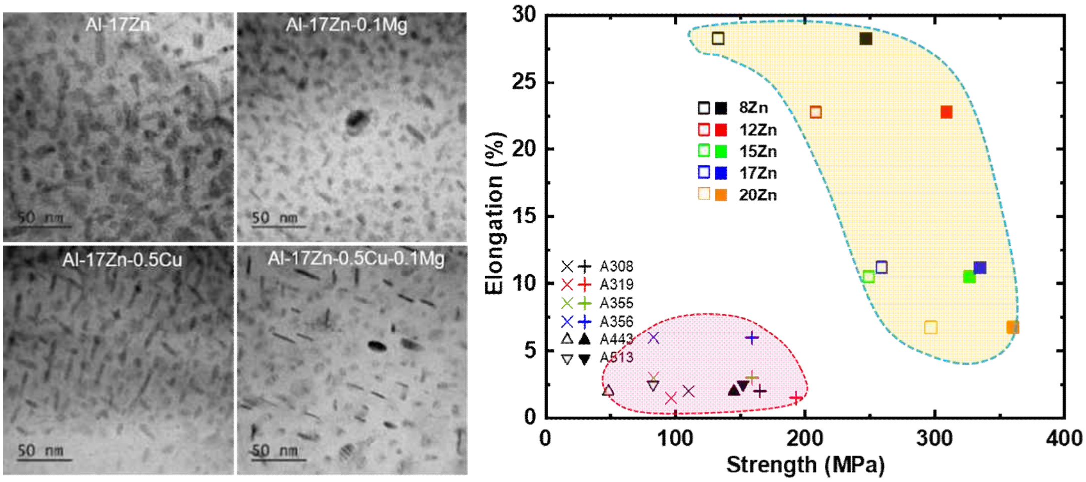

Figure 3. The microstructure of cast Al-17wt%Zn alloy with addition of Cu and Mg. And strength-elongation relation of those alloys.

REFERENCE

1. G. Kresse and J. Fürthmuller, *Phys. Rev. B* 54, 11169-11186 (1996).
2. S. Z. Han, B. Ryu, I. Jeong, S. H. Lim and E.-A Choi, Materials & Design 244 (2024) 113140.

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마그네슘 합금 판재의 R-value와 성형성간의 상관관계

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The relationship between R-value and formability in Mg alloy sheets

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ABSTRACT

Poor formability of Magnsium alloy sheets is one of the critical issues for broadening of the applications for Mg alloy sheets in industries. The relationship between r-value and formability in Mg alloys, however, is not clearly understood to date. This present work investigated the correlation of r-value with alloying composition, initial texture and formability in Mg-Al-Zn-Ca or Mg-Al-Zn-RE alloy sheets, which have strong basal texture or weak TD-split texture.

1. 서 론

구조재료용 금속소재는 두께방향보다는 폭방향의 변형으로의 변형량이 높은 경우, 즉 r-value가 높은 경우에 높은 성형성을 나타낸다 [1, 2]. 하지만 마그네슘 합금은 낮은 r-value를 갖는 합금이 더 좋은 성형성을 보여준다. 상온에서의 낮은 성형성이 마그네슘 합금 판재의 중요한 이슈 중에 하나임에도 불구하고 r-value와 성형성에 관한 연구가 미비한 실정이다. 따라서, 본 연구에서는 마그네슘 합금에서의 r-value에 영향을 끼치는 인자들에 대해서 알아보고, 이러한 r-value가 성형성에 미치는 원인에 대해서 고찰하고자 한다.

2. 결과 및 토론

그림 1a는 마그네슘 15종 합금의 합금 및 방향별 균일 연신율에 따른 r-value 측정 결과를 보여준다. 균일 연신율이 증가함에 따라서 r-value가 증가하는 현상은 일반적으로 마그네슘 합금에서 나타나는 현상과 동일하였다. 흥미롭게도 약한 집합조직을 보이는 Ca이 첨가된 1C, 4C, 5C 합금은 전체적으로 낮은 r-value 값을 갖는 것을 확인할 수 있었다. 조금 더 자세히 r-value 값을 관찰하기 위하여 그림 1b와 같이 Ca이 첨가된 합금, Al/Zn의 양이 1wt.%인 합금(1Al), Al/Zn의 양이 0.5wt.%(0.5Al)인 합금으로 구별하여 변형율에 따른 r-value를 관찰하여 보았다. 변형 초기 r-value는 모두 1보다 낮은 수치에서 시작하지만 강한 집합조직을 보이는 1Al, 0.5Al 합금들은 방향별로 변형율이 증가함에 따라서 증가하는 형태가 다르게 나타났고, 약한 TD-split 집합조직을 보이는 Ca이 첨가된 합금은 방향에 무관하게 크게 증가하지 않고 1에 가까운 수치로 유지되는 것을 확인할 수 있었다. 또 한가지 특이한 점은 TD방향으로 인장시 1Al과 0.5Al이 변형량에 따라서 증가하는 폭이 차이가 많이 났다는 점이다. 이렇게 합금에 따라서 r-value가 나나타는 원인은 초기 집합조직 차이로 인한 basal <a> slip에 의한 Schmid factor의 차이가 가장 큰 것으로 확인되었고, 동일한 초기 집합조직을 가지더라 pyramidal <c+a> slip의 활성화에 따라서 변형량이 증감함에 따라서 r-value가 크게 차이날 수 있음을 확인할 수 있었다.

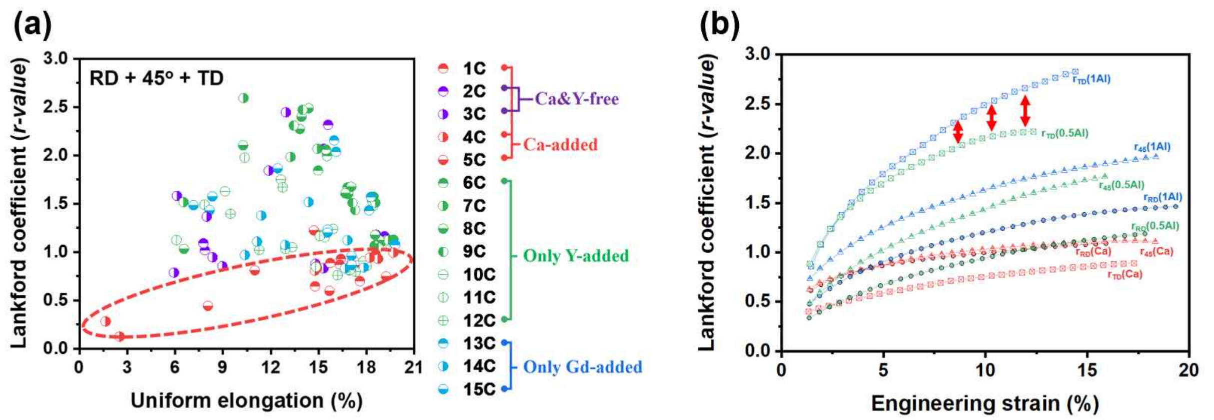

그림 58 (a) 균일연신율에 따른 합금별/방향별 r-value, (b) 1C, 7C, 10C 합금의 방향별 변형량에 따른 r-value

3. 결론

본 연구에서는 초기 집합조직, 슬립 시스템의 Schmid factor가 r-value에 미치는 영향을 확인하였고, 이를 통하여 r-value와 성형성간의 상관관계를 규명함으로써 마그네슘 성형성 향상을 위한 합금 및 집합조직 제어를 통하여 r-value를 제어하고 성형성을 향상시킬 수 있는 방법을 제시하였다.

[1] H. Liu, H. Li, C. Liu, J. Wu, Materials Engineering and Performance 33 (2024)
[2] D. Anderson, B. Raeisinia, Materials Science and Engineering 418 (2018)

제 38회 첨단구조재료 심포지엄
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- Session 3
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전류 처리에 의한 선택적인 탄화물 변화 동역학 향상 연구

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Study on selective enhancement of carbide evolution kinetics
by electric current treatment

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ABSTRACT

Electric current treatment (ECT) can be an effective alternative to conventional heat treatment (CHT) due to the athermal effect of the electric current, which enhances microstructural evolution kinetics in metals such as phase transformation [1], precipitation [2], dissolution [3], and recrystallization [4]. However, research on the athermal effect on carbides with low electrical conductivity has been insufficient. This study investigated the athermal effect on phase transformation, precipitation, and dissolution kinetics of carbides in a Fe-Cr-Ni alloy.

ECT and CHT were conducted on specimens at the same temperature to distinguish the athermal effect from the Joule heating effect. The phase evolution and elemental distribution of ECTed and CHTed specimens were comprehensively characterized by X-ray diffraction, electron backscatter diffraction, and electron probe micro-analyzer techniques. Additionally, finite element method simulations were performed to investigate the underlying mechanisms.

The results showed that ECT significantly accelerated the phase transformation of Cr_7C_3 carbides into more stable $Cr_{23}C_6$ carbides compared to CHT. Furthermore, the nucleation and growth of $Cr_{23}C_6$ in the metal matrix were notably accelerated under ECT. These accelerations were attributed to atomic diffusion enhancement by the charge imbalance effect on the phase boundaries between metal matrix and Cr-carbides [5]. In contrast, ECT didn't promote the dissolution of thermodynamically

unstable NbC phases. It was confirmed that the charge imbalance effect on NbC dissolution was limited as the $Cr_{23}C_6$ with low electrical conductivity was precipitated between the NbC and metal matrix, which blocked the electric current.

This finding suggests that the kinetics enhancement by the athermal effect can be differentiated depending on the arrangement of constitutive phases in the microstructure. By utilizing this characteristic, it is expected that a special microstructure can be designed by ECT, which cannot be achieved by CHT.

References

[1] Jeong, H. J., Kim, M. J., Choi, S. J., Park, J. W., Choi, H., Luu, V. T., ... & Han, H. N. (2020). Microstructure reset-based self-healing method using sub-second electric pulsing for metallic materials. Applied Materials Today, 20, 100755.

[2] Jeong, H. J., Park, J. W., Shin, E., Woo, W., Kim, M. J., & Han, H. N. (2022). Electric current-induced precipitation hardening in advanced high-strength steel. Scripta Materialia, 220, 114933.

[3] Jeong, H. J., Kim, M. J., Park, J. W., Yim, C. D., Kim, J. J., Kwon, O. D., ... & Han, H. N. (2017). Effect of pulsed electric current on dissolution of Mg17Al12 phases in as-extruded AZ91 magnesium alloy. Materials Science and Engineering: A, 684, 668-676.

[4] Jeong, K., Jin, S. W., Kang, S. G., Park, J. W., Jeong, H. J., Hong, S. T., ... & Han, H. N. (2022). Athermally enhanced recrystallization kinetics of ultra-low carbon steel via electric current treatment. Acta Materialia, 232, 117925.

[5] Kim, M. J., Yoon, S., Park, S., Jeong, H. J., Park, J. W., Kim, K., ... & Han, H. N. (2020). Elucidating the origin of electroplasticity in metallic materials. Applied Materials Today, 21, 100874.

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Ni기 초내열합금 IN617의 보론 첨가에 따른 1273 K 크리프 특성과 Ni 합금의 격자 수축 현상 분석

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Creep properties of Ni-based superalloys (IN617, IN617B) at 1273K with a small amount of boron and observation of its negative creep deformation

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ABSTRACT

A minor addition of boron is known to increase the creep resistance of Ni-based superalloys, and its underlying mechanism has been the subject of a number of research activities. In this study, we conducted creep experiments on Inconel 617 alloys with different boron contents. The experiments were conducted using conventional commercial creep testing machines at 973 K and custom-made equipment at 1273 K. Under two different temperature conditions, the addition of a small amount of boron demonstrated superior resistance to creep. However, it was observed that at 1273 K, the effect of boron addition turned out not to be as effective as in the case of 973 K, which has also been reported in other reports. Moreover, we found that strain data exhibited deformation in the compressive direction, indicating negative creep, regardless of the boron content during the first creep stage in both temperature conditions. Lattice contraction was observed and quantitatively measured by using the

Nelson-Riley function from XRD data. Changes in lattice constants are considered the primary cause of the negative creep phenomenon. EBSD-EDS was conducted for microstructural analysis, and it was found that variations in the phase fraction of chromium precipitates within and between grains were not the dominant contributing factor for the negative creep behavior. Nevertheless, by a detailed examination of HR-TEM, a localized region having different high-resolution lattice patterns from the surrounding matrix area has been spotted, which might suggest a short-range ordering phenomenon possibly leading to the lattice contraction.

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SA508 Gr.1A 저합금강 배관재의 파괴인성에 미치는 상분율의 영향

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Effects of phase fraction on fracture toughness of SA508 Gr.1A low-alloy steel

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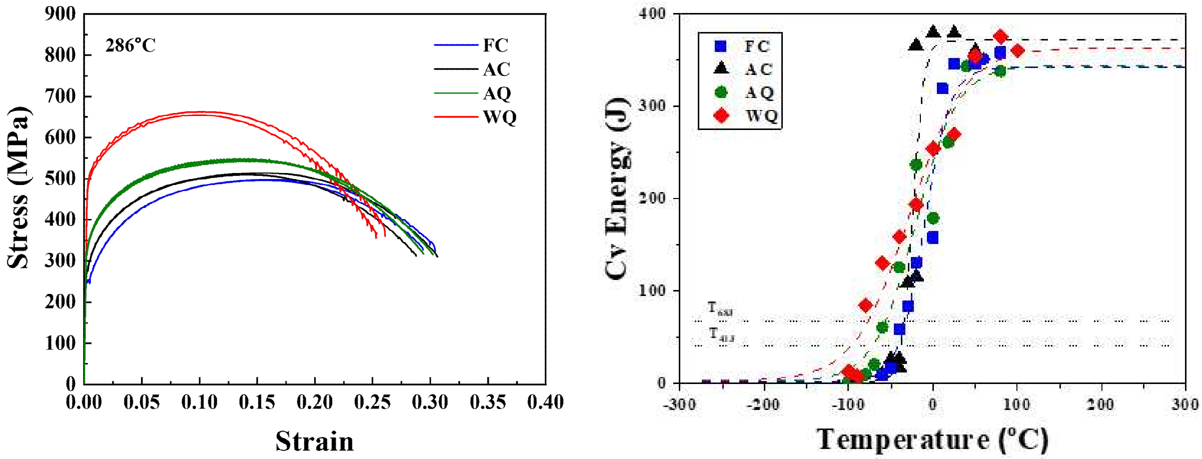
ABSTRACT

원자력발전소의 배관은 고온 고압의 증기와 냉각수가 이동하는 통로로써, 가동 환경에서 배관의 안전성을 향상시키기 위하여 우수한 파단전누설(Leak Before Break, LBB) 안전여유도를 확보하는 것이 필요하다. LBB 개념은 배관이 파단에 이르기 전에 발생하는 누설을 감지하고 적절한 조치를 취함으로써 배관의 양단순간과 같은 극단적인 상황을 방지할 수 있다. 이러한 LBB 개념을 배관에 적용하기 위해서는 충분한 LBB 안전여유가 만족되어야 한다. LBB 안전여유도는 인장특성과 J-R 파괴저항성에 주로 영향을 받는 것으로 알려져 있으며, 충분한 LBB 안전여유도를 확보하기 위해서는 항복강도 및 J-R 파괴저항성을 향상시켜야 한다.

원자력발전소 2차측 주증기배관에는 SA508 Gr.1A 저합금강이 사용되고 있으며, 오스테나이트화 열처리 후 수냉과 템퍼링을 수행하여 제작된다. 이때 배관의 두께에 따라 냉각속도가 변화하게 되고, 이로인해 미세조직의 차이가 발생한다. 따라서 원하는 기계적 특성을 가지는 배관재의 제작을 위해서는 냉각속도의 변화가 미세조직 형성에 미치는 영향과 그 결과로 나타나는 기계적 특성 변화 연구가 수행되어야 한다. 일반적으로 압연 및 단조강은 변형을 받아 연신된 오스테나이트에서 상변태가 먼저 발생하기 때문에 상태도만으로 생성되는 미세조직을 예측하기 어렵다. 기존에는 미세조직의 구별이 뚜렷한 소재를 이용한 연구들이 많이 수행되었으나, 두가지 이상의 상을 갖는 저합금강 소재의 상분

율에 따른 특성변화에 관한 연구는 부족하다.

본 연구에서는 냉각속도에 따른 SA508 Gr.1A 저합금강의 미세조직 변화와 그에 따른 파괴인성의 변화를 평가하고자 하였다. 이를 위해 소형 블록을 이용하여 오스테나이트화 이후 FC, AC, AQ, WQ으로 냉각속도를 조절하여 열처리를 수행하였다. 냉각속도에 따른 상변태 거동을 확인하기 위해 실제 열처리 블록의 냉각속도와 동일한 0.3°C/s, 1.2°C/s, 15°C/s의 냉각조건에서 딜라토미터를 이용하여 열팽창률의 변화를 측정하였다. 딜라토미터 분석을 통하여 0.3°C/s과 1.2°C/s의 조건에서는 페라이트와 펄라이트, 그리고 베이나이트의 혼합조직이 일어나고, 15°C/s의 급냉조건에서는 대부분 저온변태상인 베이나이트와 마르텐사이트 변태가 일어나는 것으로 나타났다. 주증기배관의 사용온도인 286°C에서의 인장 및 J-R 파괴저항성은 냉각속도가 증가함에 따라 저온변태상 분율의 증가로 항복강도, 인장강도 그리고 J-R 파괴저항성이 향상되었다. 그러나 냉각속도가 가장 빠른 WQ의 조건에서는 동적변형시효 현상이 유발되어 다른 냉각조건보다 강도는 크게 증가한 반면 J-R 파괴저항성은 가장 낮게 나타났다. 저온에서의 파괴인성 실험 결과, 냉각속도가 가장 느린 FC의 조건에서 조대한 펄라이트의 형성으로 충격천이특성 및 천이영역 파괴인성이 가장 낮게 나타났다. 반면, WQ의 조건에서는 T_{41J}, DBTT 그리고 참조온도 T_0 값이 가장 낮게 나타나며 파괴인성이 크게 향상되었다.



(a) (b)

그림 1. 냉각속도에 따른 (a) 응력-변형률 곡선과 (b) 충격천이특성 곡선

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고온 응용 분야용 경량/저비용 페라이트계 중엔트로피 초합금 개발

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Developing the lightweight/cost-effective ferritic medium entropy superalloys for high temperature application

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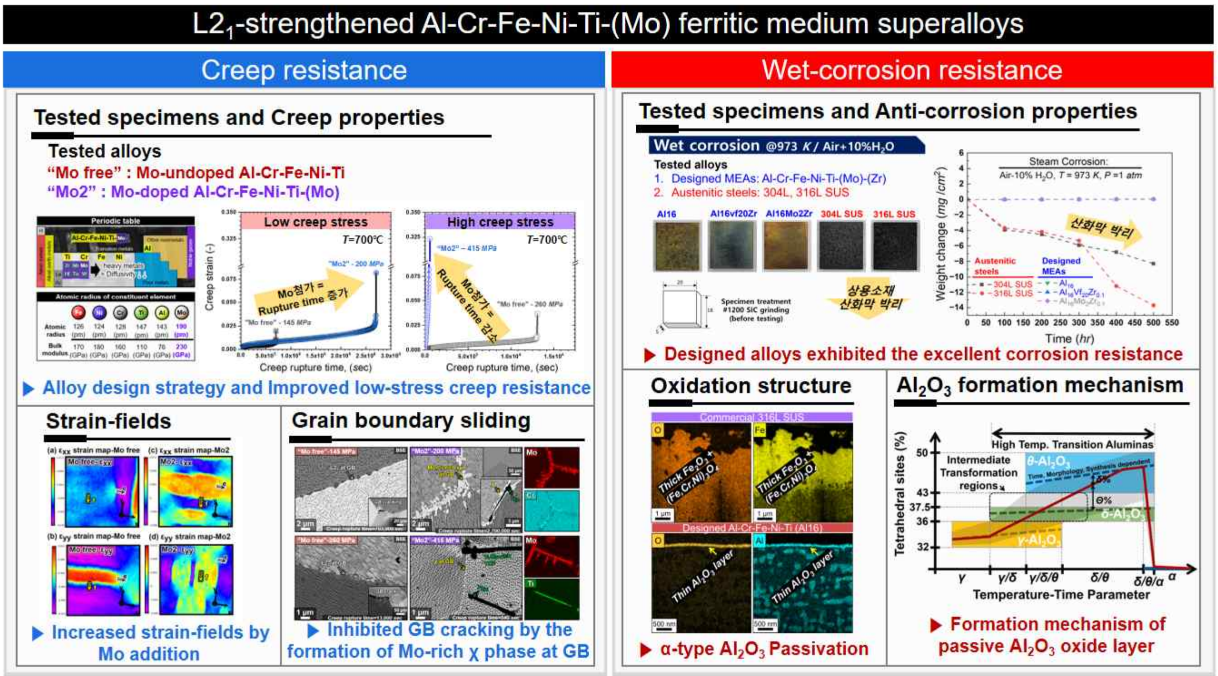
ABSTRACT

Among the major strengthening contributors, the precipitation hardening has considered as a one of the most important factors controlling mechanical strengthening and durability. Typically, the long-range $L1_2$-ordered face centered cubic (fcc) precipitates in A1-disordered fcc matrix have been highly utilized in Ni-base superalloys for high temperature application due to coherent inter-phase or interface-induced the decrease of dislocation motion, and their prolonged phase stability. However; in recent years, the price of major constituent elements of Ni-base superalloys such as Ni or Co become more costly due to the rapid increase of demands from the battery or functional industrial fields, limiting the economical application.

In the meantime, the novel alloy design concept of high/medium-entropy alloys

(H/MEAs) have been attracted by various promising physical properties such as excellent tensile properties, fatigue-, oxidation-, and irradiation-resistances, which enabled to understand the phase stability or deformation mechanism of previously undiscovered multicomponent alloys or phases. In view of this, the series of $L2_1$-strengthened Al-Cr-Fe-Ni-Ti-(Mo) ferritic medium entropy superalloys are newly designed for tailoring the optimum performance in terms of cost and mechanical/anti-oxidation properties at high temperature around 700 Celsius, and they have considered as a potential candidate for next generation power systems in extreme environment such as small modular reactors (SMRs), including molten salt reactors (MSRs), and hydrogen/ammonia firing gas turbine. Novel alloys, made using high-entropy technology, have both excellent heat and corrosion resistance due to the coherent L21 precipitates and high contant of aluminum. Fe-based ferritic mid-entropy superalloys containing high Al content also provides light-weight and cost-effectiveness. Here, we introduced the systematic research on developing the lightweight and/or cost-effective ferritic medium entropy superalloys in terms of creep, wet-corrosion resistances comparing to some of Ni-base superalloys and Fe-base stainless steels.

Graphical Abstract



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문헌조사 기반 크리프 수명 데이터의 필터링 및 장기 수명 예측 기법

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Methodologies for Multi-Source Collected Creep Data Screening and Long-Term Creep Life Prediction

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ABSTRACT

A machine learning-based data preprocessing methodology was proposed to eliminate outliers (or noises) for the creep data collected from various literature survey. Here, CMSX-4, a second-generation Ni-base single crystal superalloy, was chosen as a target material for the creep data collection, since its creep data were relatively readily available from a variety of previous studies. In addition, diffusion model, a state-of-the-art generative artificial intelligence (AI) algorithm, was adopted, for the first time, to generate the synthetic creep data for the prediction of the long-term creep life after training the model only with the short-term creep data, and its validity was assessed in detail.

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페라이트스테인리스강 및 초내열합금에서 고속영역에서 셀응고의 특성과 이론적 분석

Theoretical Analysis of Cellular Solidification in Ferritic Stainless Steels and Superalloys

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응고속도가 증가함에 따라 고상/액상 계면 형상은 평면형에서 셀형, 수지상 응고조직으로 바뀌며, 더욱 응고속도가 빠른 급냉응고 영역에서는 수지상 계면이 다시 셀형형, 최종적으로 평면형 계면이 형성된다. 빠른 응고 속도에서 형성되는 셀 응고조직을 고속 셀(high velocity cell)이라고 명명된다. 평면형에서 수지상으로 응고계면 변화는 실험적으로 planar stability이론으로 잘 설명되고 있다. 고속 영역에서 수지상으로부터 셀형, 평면형 계면으로 변화는 실험적으로 3D프린팅 공정인 additive manufacturing(AM) 및 melt spin 공정에서 보여지고 있고, marginal stability 이론으로 설명되고 있으나 고속셀 형성은 셀형상의 정확한 모델링이 어려워 이론적으로 규명이 명확히 되지 않고 있다. 본 연구에서는 고상액상 응고구간이 작은 합금인 18Cr 페라이트 스테인리스강에서 비교적 낮은 냉각속도에서 보여지는 고속셀조직과, IN901초내열합금의 AM공정에서 빠른냉각속도에서 보여지는 미세수지상/셀 조직을 응고계면 온도계산과, 평면형/비평면형(marginal stability)응고이론 계산으로 비교 분석하였다.

응고구간이 작은 합금으로 18Cr 페라이트 스테인리스강(Cr 17.9, C 0.0007, Si 0.019, Mn 0.023, Ni 0.014, Fe bal. wt.%)를 저속 및 중속에서 일방향응고 하였고, 응고구간이 큰 일반 상용합금인 IN901합금(Ni 42.5, Cr 12.5, Mo 5.7, Ti 2.8, Al 0.2, C 0.05, Fe bal. wt.%)을 일방향응고, TIG(Tungsten Inert Gas)용접, AM DED(Direct Energy Deposition)으로 실험하여 저속에서 빠른 응고속도에서의 응고조직을 관찰하였다.

그림 1에는 일방향응고 속도 10-100um/s에서 고상액상 계면조직을 보여주고 있다. 응고속도가 증가함에 따라 평면형조직에서, 셀조직, 수지상조직, 셀조직을 보여주고 있다. 50um/s에서 수지상조직, 100um/s에서 셀조직을 보여주어 이는 낮은 응고속도 영역에서 형성된 고속셀로 예상된다. 그림2에는 DED와 TIG 용접조직을 보여주고 있다. TiG조직은 수지상의 용접조직을 보여주고 있고, DED조직은 셀조직에 가까운 미세한 수지상조직을 보여주었다. 응고속도가 고속셀 까지는 못 미치는 것으로 예상된다. Fe-18Cr 스테인리스강에서 속도에 따른 응고계면 형성온도를 Fe-Cr이원계에서 계산하였다.

응고계면 팁온도는 평면형계면은 평면형 임계 속도(조성적과냉), 셀형은 셀길이에 따른 온도구배가 적용되었고, 수지상팁 온도는 팁의 조성 및 곡율에 따른 과냉이 적용되었다(그림3(a)). 매우 작은 응고구간에서는 평면형계면이 비교적 빠른 속도까지 형성되었고, 수지상형성 후 수지상 온도

가 비교적 빨리 떨어짐을 알 수 있었다 (검은색 점선). 고속셀은 수지상 팁의 온도가 떨어지면서

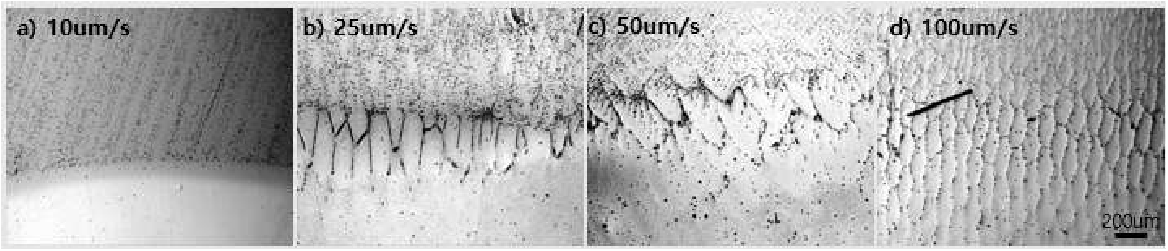

Fig. 1. Solid/liquid interface morphologies with solidification velocities at a) 10um/s, 25um/s, c) 50um/s, d) 100 um/s in Fe-18Cr-3Al alloy.

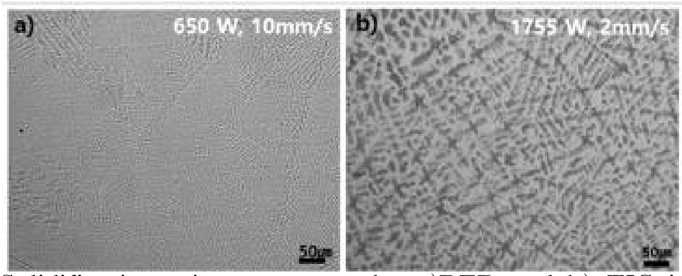

Fig. 2. Solidification microstructures by a)DED and b) TIG in IN901.

T_0에 접근하며 형성될 수 있어, Fe-Cr 같이 응고구간이 짧은 상태도에서는 고속셀이 비교적 느린 속도인 100um/s에서도 형성될 수 있음을 보여주었다. 그러나 명확히 고속셀 형성을 규명하기 위해서는 셀팁의 온도 예측 모델이 요구되나 아직 셀팁의 조성 및 온도 분포에 대한 신뢰성있는 모델이 설정되지 않고 있다. 그림 3(a)에서 속도에 따른 셀팁이 적용된다면(빨간점선, Cell tip(expect)) 수지상에서 고속셀의 형성을 명확히 예측할 것으로 예상된다, IN901합금의 TIG, DED 응고조직에 고속셀 형성을 Marginal stability 이론을 적용하여 온도구배와 응고속도에 따른 Planar/Non planar 계면 조건으로 분석하였다(그림3 (b)). 이 평면형/비평면 계산 도표에 일방향 응고조직은 평면형, 셀, 수지상조직으로 비교적 낮은 GV 영역에, TIG는 중간의 GV 영역에, DED는 중상의 GV 영역에 위치함을 보여주었고, DED 응고조직은 고속평면형, 고속셀영역에 미치지 못함을 보여주었다. 실제 DED 미세조직은 셀조직에 가까운 미세한 수지상으로 나타났다.

응고구간인 짧은 상태도 합금에서는 느린 응고속도에서 고속셀 조직이 형성될수 있고, 응고구간이 큰 상태도 합금에서는 급냉응고 조건에서 형성될 수 있음을 응고이론으로 분석하였으나, 신뢰성 있는 셀팁의 조성 및 온도 모델링과, 급냉응고 영역에서 고속셀 및 평면형 계면의 실험적 결과를 확보위해 지속적 연구가 필요하다.

a) b)

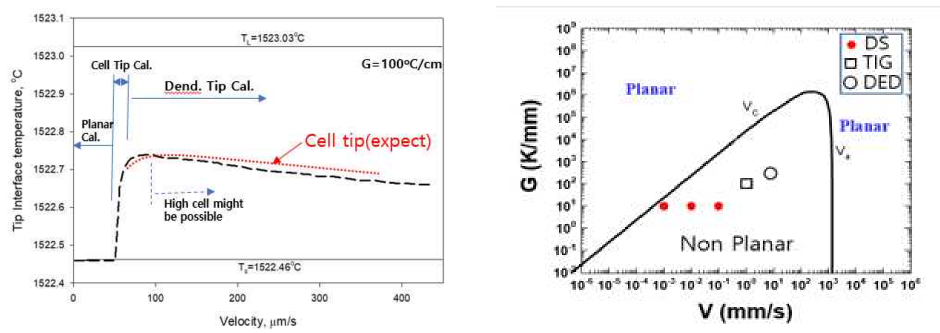

Fig. 3. (a) Primay solidification tip selection with V by interface tip temperature calculation in Fe-10Cr binary and (b) planar/non planar solidification with G and V by marginal stability in IN901.

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Random Multimodel Deep Learning (RMDL)을 활용한 초내열합금의 제2상 분석

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Analysis of the Secondary Phases in Superalloys Using Random Multimodel Deep Learning (RMDL)

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1. 서론

최근 인공지능 기술의 발달로 다양한 재료의 특성을 분석하는 데 있어 이미지 분석 기술이 중요한 역할을 하고 있다. 특히, 초합금의 제2상 분석은 기계적 특성 예측 및 열화 평가를 위해 필수적인 과정이다. 그러나 기존의 이미지 분석 방법은 불완전한 데이터로 인해 효율성이 떨어지거나 정확한 분석이 어려운 경우가 많다. 기 발표[1]에서는 기본적인 Transfer learning 기술[2]을 활용할 경우 간단하면서 매우 만족스러운 성과를 얻을 수 있음을 보여주었다.

본 연구에서는 다양한 앙상블 모델 중 하나로 제안된 Random Multimodel Deep Learning (RMDL) 접근 방식[3]을 활용하여 다양한 모델을 조합한 앙상블 학습을 통해 초합금의 제2상 분석의 정확도를 높이고자 한다.

이러한 RMDL 기술은 개별 모델의 한계를 극복하고 다양한 모델의 장점을 결합하여 높은 성능을 달성할 수 있으며, 항공우주, 에너지, 자동차 산업 등에서 고성능 소재의 설계 및 최적화를 위해 매우 유용하게 활용될 수 있다.

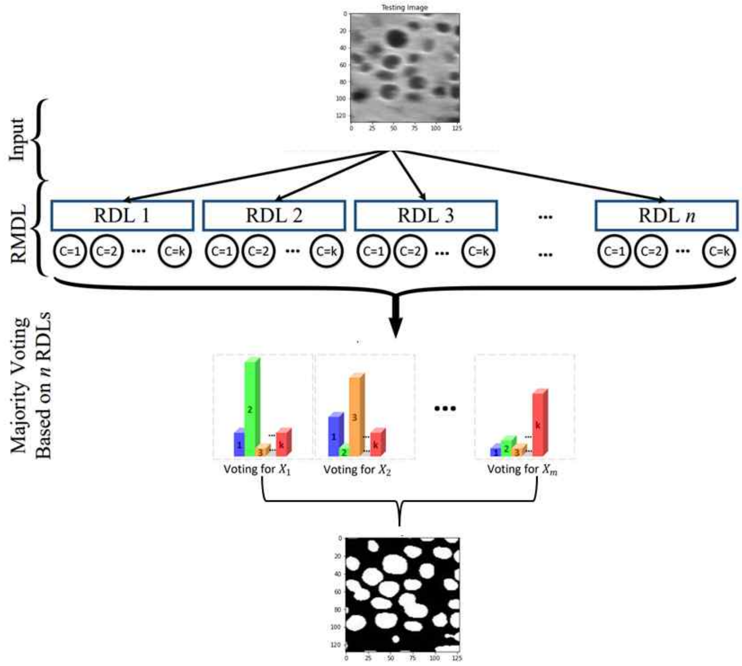
2. 방법

RMDL 접근 방식은 다양한 모델을 조합하여 학습하는 방식으로, 각 모델은 서로 다른 백본 네트워크를 가질 수 있다. 본 연구에서는 ResNet50, VGG16, InceptionV3 등 다양한 모델을 이용해서 모델을 무작위로 선택하여 앙상블 학습을 수행하였다. 이를 통해 각 모델의 장점을 결합하여 최종 예측의 성능을 향상시켰다. 또한, 데이터 증강 기법을

활용하여 학습 데이터의 다양성을 높이고 모델의 일반화 성능을 강화하였다. 할 수 있어 매우 유용한 기술이다.

3. 결과

RMDL 접근 방식을 통해 단일 모델을 사용하는 경우보다 높은 정확도를 얻을 수 있었다. 단일 모델의 경우 평균 IoU 점수보다 RMDL 모델의 경우, 세 모델을 조합한 앙상블 학습을 통해 평균 IoU 점수가 향상되었다. 이는 다양한 모델의 장점을 결합하여 성능을 극대화할 수 있음을 보여준다.



4. 요약

1. RMDL 접근 방식을 통해 다양한 모델의 장점을 결합하여 초합금의 제2상 분석의 정확도를 높일 수 있다.
2. 단일 모델보다 앙상블 학습을 통해 높은 정확도를 달성할 수 있으며, 이는 다양한 백본 네트워크를 활용한 결과이다.
3. 데이터 증강 기법을 활용하여 적은 수의 학습 데이터를 활용해서 높은 성능의 얻을 수 있다.
4. RMDL 기술은 특히 다양한 모델의 융합을 통해 더욱 정교한 분석과 예측이 가능하다

참고문헌

1. 공병욱, 주윤곤, 김병훈, 이재현, 첨단구조재료심포지엄 (2023)
4. https://www.tensorflow.org/tutorials/images/transfer_learning?hl=ko
3. K. Kowsari. et.al, CISDM '18, April 9 - 11, 2018, Lakeland, FL, USA

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실험계획법과 인공신경망을 활용한 고온 내산화성이 향상된 초내열합금의 개발

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Development of Superalloy with Improved High-Temperature Oxidation Resistance Using Design of Experiment and Artificial Neural Network

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ABSTRACT

Superalloys are one of the most important material as a high-temperature structural material, and are used in various fields such as gas turbines, energy plants, and chemical plants. In the development of superalloys as high-temperature structural materials, various properties such as high-temperature strength, creep strength, fatigue properties, and high-temperature oxidation resistance must be considered. However, since many alloying elements such as Cr, Al, Ti, W, Mo, Ta, and so on are often added to superalloys, it is very challenging to develop an alloy while balancing all these properties. In this study, we utilized design of experiment(DoE) and artificial neural network(ANN) in developing Ni-base single crystal and wrought superalloys with improved oxidation resistance.

In order to apply machine learning methods such as ANN for alloy development, a high-quality database is required. For mechanical properties, a relatively large amount of good quality data can be collected from the literature. However, in the case of high-temperature oxidation resistance, there are no standardized specimen specifications or methods, so that the experimental conditions are different depending on the literature. Therefore, it is required to build a database through experiments. To obtain a high-quality database with minimal experimentation, Box-Behnken method among DoE was used.

In the development of single crystal alloy, seven elements, Cr, Al, W, Mo, Ta, Re,

and Ru, were set as variables, and the properties were measured by changing them at 3 levels. When experimenting with full factorial design, 2187 experiments are required. However, ANN modeling can be applied with 62 experiments by using the Box-Behnken method. Fig. 1 show ANN modeling results and high-temperature oxidation property of the developed alloy.

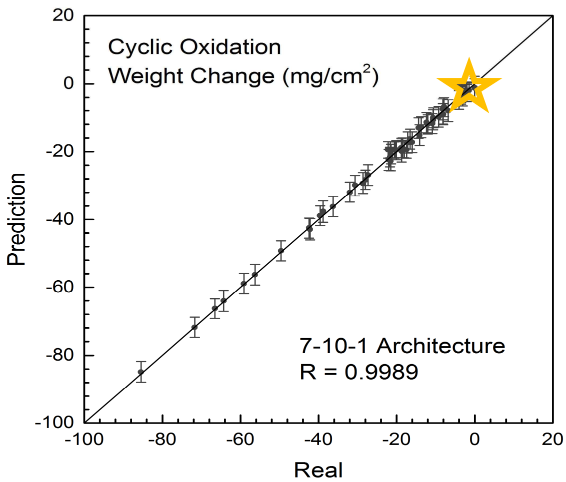

Fig. 1 ANN modeling results and high-temperature oxidation property of the developed alloy(star)

In the development of wrought alloy, seven elements, Cr, Co, Mo, Nb Ti, Al, and Si, were set as variables, and the properties were measured by changing them at 3 levels. Fig. 2 show ANN modeling results and high-temperature oxidation property of the developed alloys.

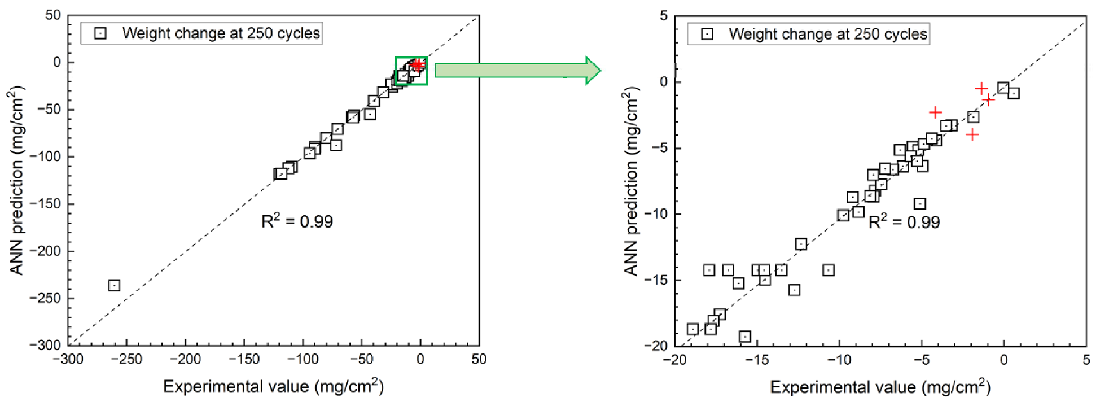

Fig. 2 ANN modeling results and high-temperature oxidation property of the developed alloys(cross)

Alloys with improved high-temperature oxidation resistance was successfully developed using Doe and ANN. It is expected that this method can be used in various fields such as heat treatment and process development.

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COD 게이지 없이 피로균열성장 시험을 수행하는 혁신 기술

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An innovative technology for fatigue crack growth testing without gauge attachment

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ABSTRACT

Fatigue crack growths (FCG) are generally measured using the standard unloading compliance method with a COD gauge. In this paper, the changes in unloading compliance during an FCG test are measured by the stroke displacement at a remote load-line position. The measured stroke data of the test system at this remote position are transformed into the compliances of the test specimen by compensating for the in-situ nonlinear machine compliance within the applied load range. A software program was developed to implement the proposed theory into FCG testing. The accuracy of the estimated crack lengths is comparable to the results obtained using a COD gauge and 9-point optical measurements. Two practical applications are demonstrated: (1) FCG testing at high temperatures and (2) an automated fatigue pre-cracking system.

1. 서론

ASTM E647 표준시험법에 따라 일정 하중진폭하의 피로균열성장 시험을 수행할 때 핵심사항은 피로균열진전량의 정확한 측정이다. 대표적인 측정방법으로는 COD 게이지를 이용한 탄성해중(unloading compliance) 방법이 표준화되어있으며, 경우에 따라 원거리현미경을 이용한 육안검사와 DCPD (직류전위차) 방법 등이 보완적으로 사용된다. 그러나, 탄성해중법을 적용하기 위해서는 시편의 CMOD (crack mouth opening displacement)를 직접 측정할 수 있는 COD 게이지가 절대적으로 필요하기 때문에, 고온이나 부식분위기 등 COD 게이지의 사용이 불가할 때는 적용할 수가 없었다.

본 논문에서는 일반 피로시험기의 stroke position 데이터만을 이용하여, 시험기의 시스템 컴플라이언스 영향을 소프트웨어적으로 보정함으로써, COD 게이지를 사용한 것과 거의 동등한 정확도로 피로균열 진전량을 결정하는 혁신적인 기술을 소개하고자 한다.

2. 본론

피로균열성장 시험기에서 시험편을 체결한 상태에서 시험기의 stroke 변위에 영향을 미치는 인자는 크게 세 부분으로 구분할 수 있다 (그림 1). 즉, 시험편의 균열에 작용하는 변위, 체결부 그립의 비선형 탄성변형, 그리고 시편 하중핀의 탄소성 압입이다. 시험 초기에 시스템의 전체 하중변위 선도와 피로균열성장이 발생한 후에 시스템의 전체 하중변위 선도를 상대 비교하면, 그 차이가 시험중 발생한 균열성장에 기인한 시편의 컴플라이언스 변화로 생각할 수 있다.

따라서 이 변화를 정밀하게 측정할 수 있는 소프트웨어 툴을 개발하여 실제로 피로균열성장 시험을 자동화하여 수행하고, COD 게이지 및 9-point 육안검사 결과와 비교를 통해 신기술의 유용성을 확인하였다 (그림 2).

3. 결론

본 기술의 적용을 위해 필요한 사항은 단지 시편의 정확한 탄성계수 뿐이다. 시편에 아무런 부가장치의 부착이 필요 없으므로, 고온/부식 등 극한 환경에서도 온도만 안정적으로 제어된다면 적용이 가능할 것이다. 특히, 파괴역학 시험편의 예비피로균열 자동생성 시스템으로 유용하게 사용되고 있으며, 고온에서 피로균열성장시험 적용 가능성도 실험을 통해 확인하였다.

[참고문헌]

Lee BS, et al. An innovative way to measure fatigue crack growth without COD gauge. Int J Fatigue 2024; 184: 108327

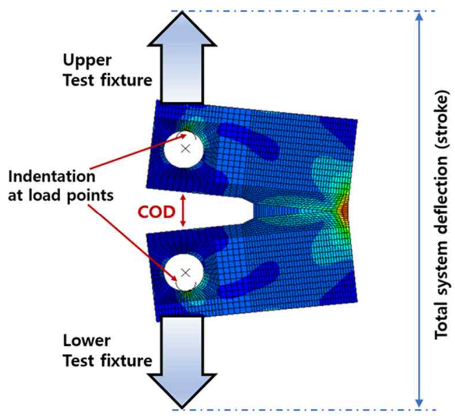

그림 1. 피로시험기에 체결된 시험편과 시험기 체결부의 총 변형 성분

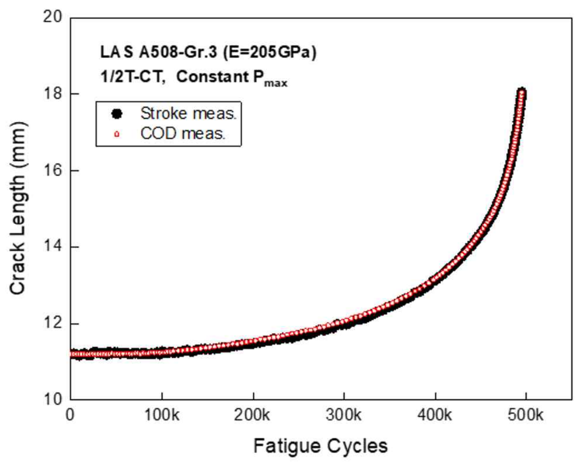

그림 2. 피로균열성장량 측정 시험 결과 (COD 게이지 결과와 비교)

Proc. of the 38th Conference on Advanced Structural Materials
Gyeongju, Korea, 29th Aug. - 30th Aug., 2024
The Korean Institute of Metals and Materials

원전 내부구조물 스테인리스강 용접부 열취화 특성 평가

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ABSTRACT

기후변화 이슈가 중요해짐에 따라 각국에서는 탄소 배출을 줄이기 위한 노력을 쏟고 있다. 이에 따라 화력발전을 줄이고 탄소배출량이 없는 원자력 발전의 활용은 필수적이고, 전세계적으로도 신규 원전 걸설 및 가동원전 수명연장을 통해 원전 활용량을 늘리려 하고 있다. 안전은 원자력 발전소에서 가장 중요한 항목으로, 기존 원전의 수명연장을 위해서는 원전 주요 기기의 건전성이 필수적으로 검증되어야 한다. 원전 기기는 장시간 가동환경에 노출됨에 따라 다양한 경년열화 현상이 나타난다. 특히 원자로 내부구조물의 경우 고온의 원전수, 장기간의 중성자 조사에 노출되는 환경에서 응력부식균열, 조사응력부식균열, 마모, 피로, 열취화, 조사취화, 기공팽창, 응력이완 크립 등의 경년열화 기구가 나타난다고 알려져 있다. 그 중 열취화/조사취화의 경우 재료 열화가 발생하지만 비파괴적 방법으로 경년열화를 진단할 수 없기 때문에 잠재열화를 고려한 결함 안정성 평가가 필수적으로 필요하다. 그 중 열취화/조사취화의 경우 재료 열화가 발생하지만 비파괴적 방

법으로 경년열화를 진단할 수 없기 때문에 잠재열화를 고려한 결함안정성 평가가 필수적으로 필요하다. 특히 CE형 원전의 내부구조물은 스테인리스강의 용접방식을 통해 제작되는데, 용접부에서 생성된 델타페라이트가 열취화를 일으키는 요인으로 알려져 있다. 또한 중성자 조사취화 현상으로 인해 강도는 증가하고 연성과 인성이 떨어진다. 최근 연구결과에서는 열취화, 중성자 취화의 시너지 효과로 인해 재료의 취화 현상이 가속화/심화 될 수 있는 잠재적 위험이 있다고 보고되고 있다. 따라서 스테인리스강의 열취화, 조사취화, 열+조사취화 영향에 대한 연구를 바탕으로 내부구조물 용접부의 건전성 평가가 수행되어야 한다. 따라서 이번 연구에서는 스테인리스강 용접부의 열취화 현상으로 인한 기계적 특성 감소를 평가하기 위해 원전 내부구조물을 모사한 용접부를 제작한뒤 400℃, 450℃에서 가속 열취화시험을 통해서 열취화 모사시험편을 제작했다. 열 취화된 오스테나이트 스테인리스강 용접부의 미세조직 분석 및 인장, 마이크로 압입시험, 충격, J-R 파괴인성과 같은 기계적특성 평가를 통해 오스테나이트 스테인리스강의 열취화 거동을 분석하였다.

소재혁신선도본부

소재혁신선도본부 본부장 | 이상관

임무와 역할

임무

소재 대외의존도 해소, **소부장 미래 경쟁력 확보** 및 생태계 강화를 위한 **소재혁신선도 플랫폼 구축**

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- 소부장 R&D 커뮤니티 활성화 (소부장 전문가협의체)

주요업무

소재·부품 핵심기술 조기 확보를 위한 R&D 정책 수립
과기부 소부장 관련 정책 수립 및 지원

소부장 관련 신규사업 발굴 및 R&D 기획
국가핵심소재, 미래소재 등 신규 R&D기획

과기부 소재 연구단 성과관리 및 지원
원천특허 확보, 기술이전, 성과홍보, 연계방안 도출 등 연구단 맞춤형 지원 (국가핵심소재연구단, 미래기술연구실)

소부장 산·학·연 협력네트워크 구축 및 운영
전문가협의체 운영 (12대 국가전략기술분야 25개 전문연구회), 소재연구기관협의회 운영

신규 R&D 발굴 및 기획 추진

미래소재 R&D (전략형)

" 국가전략기술기반 미래소재 발굴 지원 "

미래기술 연구실 확대 ▶ 차세대 유망 미래소재 선점

* 전략형(소재) 과제 : 21개 연구실('22.12) → 100개 확대 운영('25년)

| 차세대 주력산업 및 기술패러다임 변화를 주도하고 미래 소부장을 선점할 수 있는 '미래소재' 확보 추진

- 국가전략기술을 뒷받침할 수 있는 기술난제 극복 지원을 위한 "전략형" 과제 신규 기획
  - [현황] '21년 4개 전략형 시범사업 추진 / '22년 17개 전략형 과제 본격 추진

국가핵심소재 R&D (플랫폼형/특화형)

" 소부장 핵심품목의 미래지향적 기술자립 지원 "

국가핵심소재연구단 확대 ▶ 소부장 R&D핵심품목 기술자립 + 공급망 대체

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| 소재 부품 장비 R&D핵심품목 기술 및 미래선도 품목과 연계, 다양한 품목의 기술 자립을 위한 핵심기술 조기 확보 추진

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  - [현황] '21년 57개 연구단 운영 / '22년 12개 연구단 추가 운영

소재전문연구회

소재전문연구회 구성 및 운영

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분야	연구회
반도체	① 미래반도체 연구회 ② 특화반도체 연구회 ③ 첨단패키징 연구회
디스플레이	① 자유형상디스플레이 연구회 ② 초실감디스플레이 연구회 ③ 친환경디스플레이 연구회
차세대원자력	① 차세대원전소재 연구회 ② 핵융합소재 연구회
첨단 모빌리티	① 스마트모빌리티소재 연구회 ② 친환경모빌리티소재 연구회
이차전지	① 이차전지소재 연구회
수소	① 수소에너지 연구회 ② 연료전지 연구회
첨단바이오	① 생체소재 연구회 ② 헬스케어소재 연구회
우주·항공	① 극한환경소재 연구회 ② 경량소재 연구회
첨단로봇·제조	① 센서소재 연구회 ② 미래형 기판소재 연구회
차세대통신	① 초고속통신소재 연구회
양자	① 양자소재 연구회
인공지능	① AI기반 신소재 연구회
융합	① 광에너지융합소재 연구회 ② 일계물성융합소재 연구회 ③ 다기능융합소재 연구회

※ 미래소재 및 국가핵심소재 발굴에 관심이 있으신 연구자분들은 소재혁신선도본부로 연락주시기 바랍니다. 담당: 신정호 선임연구원(jhshin@kims.re.kr)

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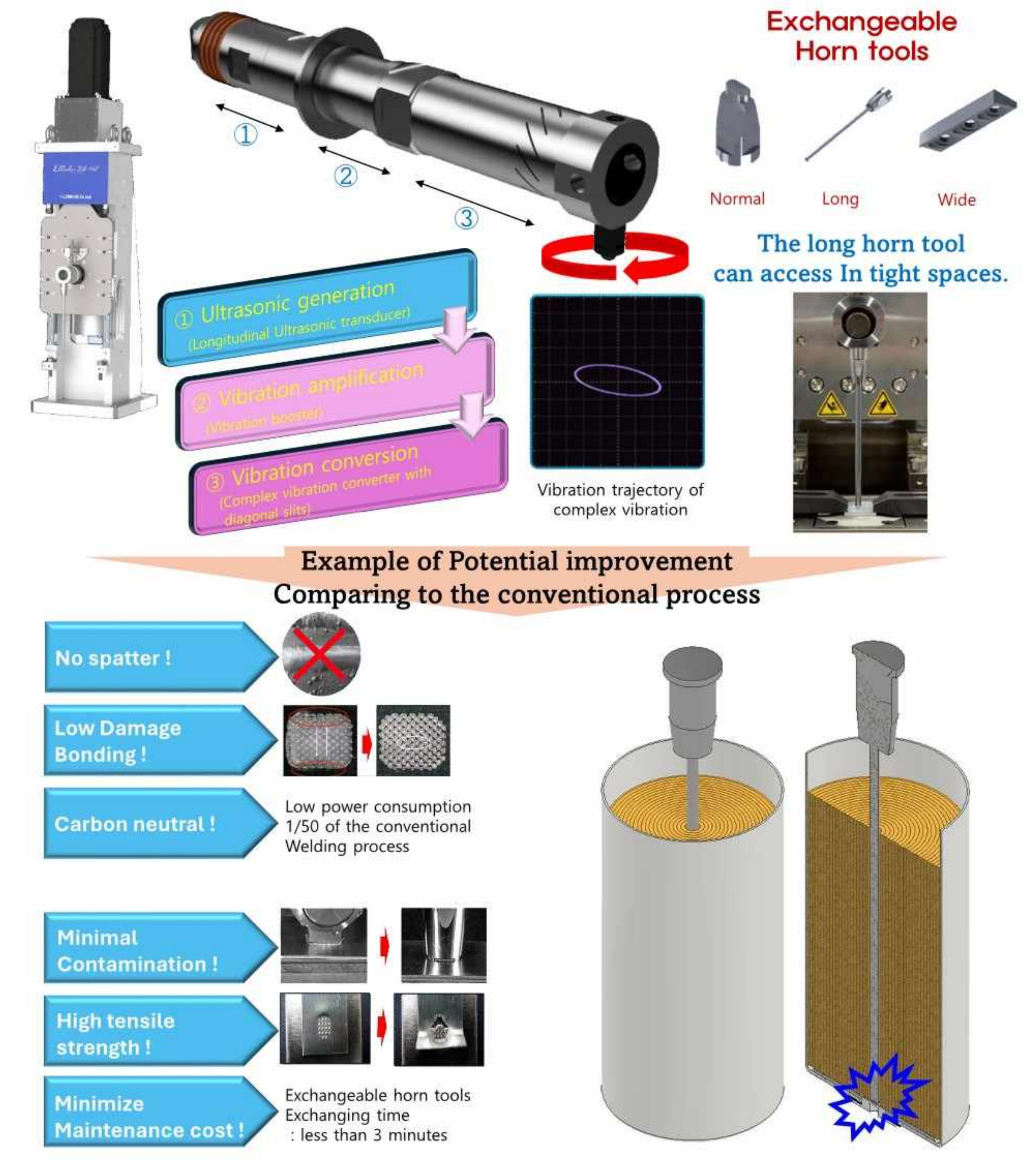
저온 충격인성 보증
우수한 용접성 유지

The Ultrasonic Complex Vibration bonding

LINK-US Co.,Ltd.
BMS engineering

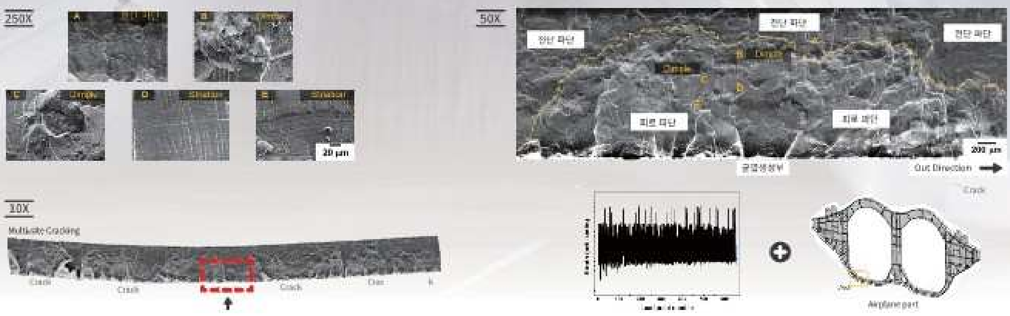


IFAA

항공우주 소재부품 손상원인분석 연구소

항공우주 및 여러 산업분야에서 발생하는
소재 및 부품의 결함이나 손상의 원인 분석

항공기 개발을 위한 Fractographic analysis의 예



Speed brake 파손 원인 분석 예

분석 사례

- 2023년 항공기 전기체 내구성 시험체 균열발생부 파면 분석(K사)
- 2019년 헬리콥터 착화서 파손 원인 분석(K사)
- 2018년 무면활동 밸브 균열 원인 분석(D사)
- 2017년 담수화플랜트 열교환기 파이프 균열 원인 분석(P사)
- 2014년 항공기 MLG shock absorber 부식원인 분석(K사)
- 2013년 담수화플랜트 벽동 배관 부식 원인 분석(P사)
- 2012년 열간 단조 단자 균열 원인 분석(K사)
- 2010년 항공기 speed brake 파손 원인 분석(K사)
- 2010년 승강기 부품 파단 분석(O사)
- 2009년 항공기 ESC duct 파손 분석(K사)
- 2009년 항공기 door stiffener 파손 분석(K사)
- 2008년 항공기 manifold clamp 파손 분석(K사)
- 2008년 항공기 pivot shaft 파손 분석(K사)

자문위원단 (가나다순)

IFAA의 분석 업무는 자문위원단 중 그 분야 전문가들로 팀이 구성되어 진행되며, 아래 명단 외에도 우주 및 항공 산업의 현장에서 종사하시는 전문가들도 다수 참여하고 있습니다.

- 강성규: 경상국립대학교 나노신소재융합공학과 교수, 연구분야 - 금속재료의 기계적 거동
- 권용남: 한국재료연구원 책임연구원, 연구분야 - 금속 소성가공, 재료 물성시험, 소재부품 파손분석
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- 이정구: 울산대학교 첨단소재공학부 교수, 연구분야 - 합금개발, 저온고상접합, 분말야금, 부식
- 이재현: 창원대학교 신소재공학부 교수, 연구분야 - 금속의 응고, 상변태
- 장재일: 한양대학교 신소재공학부 교수, 연구분야 - 재료의 기계적 거동, 나노- /마이크로- 역학 분석
- 전은채: 울산대학교 첨단소재공학부 교수, 연구분야 - 다층 소재의 특성 분석, 나노역학
- 최연주: 국민대학교 신소재공학부 교수, 연구분야 - 나노융합 구조소재
- 한승전: 한국재료연구원 책임연구원, 연구분야 - 비철금속
- 한흥남: 서울대학교 재료공학부 교수, 연구분야 - 구조용 재료의 기계적 특성


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수출액 CAGR
(2020년~2023년 기준)

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누적 매출액

Quantum Jump
고수익 창출 가능한
최첨단 산업군 본격 진출

소부장 강소기업
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뿌리기술 전문기업 지정
혁신기업 국가대표 1000기업 선정
수출유망 중소기업 지정

R&D 우수기업*
R&D 인력비중 40%
R&D 역량진단 65.9점
(대기업 평균 63.4점)

글로벌 수준 기술력
고청정 진공용해, 합금화 공정,
금속 특성 제어기술 등 세계 최고
수준의 첨단금속 제조 기술 보유

첨단금속 생산 설비
고품질 첨단금속 제조를 위한
EBCHM, PACHM 등 국내 유일 설비 보유

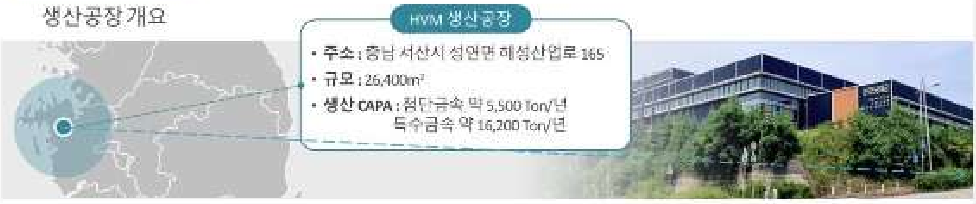
*기업부설연구소/전담부서 신고관리시스템 역량진단 기준(rnd.or.kr)

생산제품

Sputtering Target	Special Metals	Advanced Metals
		
▪ Metals for Evaporation (Cu, NiCr) ▪ High Purity Metals (99.995%)	▪ Ni Superalloys ▪ Hastelloy, Inconel, Monel ▪ Ti-, Cu Superalloys	▪ High Purity Invar for FMM ▪ Interconnects for SOFC ▪ Flexible Ti alloy

Main Products

생산공장 개요



생산설비 현황

진공용해로

용해로 특장점

PACHM
• LDI & HDI* 저감 등 불순물 제어를 통한 고청정 금속 제조 가능
• 100% 스크랩 용해 → 소재비 절감

EBCHM
• 고융점 금속(W, Ta, Nb, Mo 등) 용해 시 필수적 용해 설비
• 불순물 함량이 거의 없는 극청정 소재 제조 가능

다양한 진공용해 설비를 보유해 금속 성질에 따른 첨단금속 제조 가능

*LDI: Low Density Inclusion, HDI: High Density Inclusion

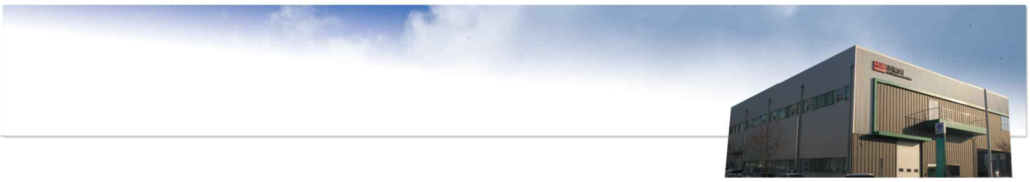
단조프레스

3,500T, 4,000T급
단조프레스 구비

4단 열간 압연기

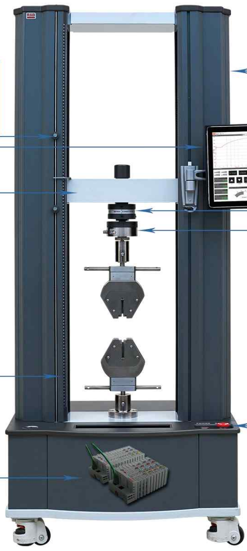
국내 최초 첨단금속 전용
광폭 4단 열간압연기 설치


PILETA
(주) 피레타
MTS
우주항공용 소재분야
고온시험 확대를 위한
산 / 학 / 연
기술교류회
우주항공, 발전용 가스터빈 및 발사체 소재는 기존 소재와 다르게 특수한 환경에 적합하도록 설계되고 제작됩니다. 특히, 고온에 견딜 수 있는 소재는 항공용 엔진, 발전용 가스터빈 및 발사체 등에 필수적입니다. 국내의 경우 고온시험의 고비용, 다수의 특수장비가 필요하며 기술적 성숙도가 낮은 상황입니다. 이러한 문제를 해결하기 위해 산업계, 학계, 연구기관이 함께 고온시험에 대한 기술교류를 진행하고자 합니다.
이번 산/학/연 기술교류회는 우주항공용, 발전용 가스터빈 및 발사체 소재의 고온시험 필요성과 중요성을 인식하고, 관련 분야의 최신 동향과 기술을 공유하며 협력 방안을 모색하고자 하오니 산/학/연 관계자의 많은 관심과 참여를 부탁드립니다.
Program
09:30~10:00 접수
10:00~10:10 Welcome (최현선 대표 - PILETA 소개)
10:10~10:40 한국항공우주산업진흥협회 신복균 지부장 - 우주항공 미래산업 현황 및 전망
10:40~11:10 창원대학교 홍현욱 교수 - 단결정 니켈기 초내열합금의 열-기계적 피로에 따른 국부 변형기구 해석
11:10~11:40 MTS Erik Schwarzkopf - Mechanical Testing of Elevated Temperature PMC, Metallic, and CMC coupons
11:40~13:00 Lunch
13:00~13:30 SGS 이상훈 박사 - 금속 및 용접재료에 관한 특성 평가
13:30~14:00 PILETA 민기득 박사 - IN718 소재 저주기 피로특성
14:00~14:30 KAERI 이봉상 박사 - COD 게이지 없이 피로균열성장 측정 시험을 수행하는 혁신 방법
14:30~14:45 Break
14:45~15:15 MTS Erik Schwarzkopf - Thermomechanical Fatigue using MTS Equipment
15:15~15:45 강릉원주대학교 최병학 교수 - 수소 취성과 시험법
15:45~16:15 국민대학교 성효경 교수 - 금속재료의 파괴인성 평가 방안
16:15~16:30 Lab tour
16:30~17:30 고온시험 및 토론
17:30~ Closing
일 정 2024년 9월 24일(화) 10:00 ~ 18:00
장 소 주식회사 피레타, 대전광역시 유성구 국제과학3로 22 (신동)
참가 신청 2024년 8월 5일(월) ~ 2024년 8월 30일(금)
pileta@pileta.co.kr 메일 신청 또는 QR코드 신청
※ 인원제한으로 인해 조기 마감될 수 있습니다.
참가 비용 무료 (중식제공)
QR코드



재료시험기, 마모시험기, Full Accessories 등 개발 및 생산

RB301 Universal Testing Machine



Stroke Limit
One-touch Stroke Limiter

Crosshead
Maximum rate*: 1,600mm/min
Minimum rate*: 0.0005mm/min

Remote Controller
Crosshead Positioning with Jog Dial
Stress- Strain Curve
Load, Strain, Displacement Display

Scale
Position of Crosshead
0.1mm Resolution

NEXCADE 7 Controller
24 bit Controller
Test with HELIO 7 Software

Aluminum Profile Case
No Rust, Fancy Design

Alignment Fixture
4 Concentricity, 4 Angularity Adjustment
Certification for ASTM E1012

Load Cell
Force accuracy is less than ±0.5% of the indicated value over the range from 0.4% of Load Capacity

Emergency Stop Button
Cuts off Power and Stopping Crosshead Moving at Emergency

Metallography 장비 및 소모품

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Dong-A Special Metal Co.,LTD.

Products Introduction

Info

Address
52013/528-16, Jangbaek-ro, Beopsu-Myeon,
Haman-gun, Gyeongsangnam-do, Republic of Korea.

Tel
+82-55-586-7391

Hompage / Email
http://www.dongaspecial.co.kr / sales3@dongaspecial.co.kr

Fax
+82-55-586-7393

Titanium Cobble


Titanium sponge


Titanium cobble


Titanium cobble puck

• Standard : JIS H2151 - Titanium sponge

	Grades	Ti (min)	Fe (max)	Mg	N	Si	Mn	C	H	O	Cl
Grade A	TST-P	99.7	0.04	0.04	0.008	0.02	0.005	0.01	0.003	0.04	0.08
	TST-1	99.7	0.04	0.04	0.01	0.02	0.005	0.01	0.003	0.05	0.08
	TST-2	99.6	0.06	0.05	0.01	0.02	0.005	0.01	0.004	0.05	0.10
	TST-3	99.4	0.08	0.06	0.01	0.02	0.010	0.02	0.005	0.06	0.12
Grade B	TAT-12 (TgTV)	97.0			0.30						

• Standard : DASM - Titanium cobble

Grades	Ti (min)	Fe (max)	Mg	N	Si	Mn	C	H	O	Cl
Ti Gr.1 cobble	Bal.	0.04	-	0.01	-	-	0.015	0.003	0.06	-
Ti Gr.2 cobble	Bal.	0.04	-	0.01	-	-	0.025	0.003	0.15	-
Off grade cobble	97.0	-	-	0.03	-	-	-	-	-	-

• Application

- A raw material for Titanium ingot (All titanium alloy)
- Alloy additivies for Super alloy_Ti contents (Inconel 792, 738LC, 939, X-750, GTD 111, Waspaloy etc)
  (Cobble puck is very useful for alloying than loose : Density 3.4)
- A Materials for additive manufacturing (3D Printing)
- Pyrotechnics as a source of bright-burning particles (Cobble powder)
- A Raw material for HDH powder

DONG-A SPECIAL METAL