A Study of Super-plasticity in Low Density Steel Sheet

Junyeong Jeong[1)*] **Jaeyoon Hwang**[1)] **Minwoo Kang**[1)] **Jeongho Han**[2)]

1) R&D Division, Hyundai Motor

150, Hyundaiyeonguso-ro, Namyang-eup, Manse-gu, Hwaseong-si, Gyeonggi-do, Republic of Korea, 18280 (jjy9889@hyundai.com)

2) Division of Materials Science and Engineering, Hanyang University, Seoul 04763, Republic of Korea

10-3 Gobancho, Chiyoda, Tokyo, 102-0076, Japan

KEY WORDS: Low Density Steel, Super-plasticity, Duplex microstructure, High temperature tensile property

This research paper investigates the superplastic properties of Fe-Mn-Al-C series low-density steel sheets, which are lightweight alternatives to traditional high-strength steel and aluminum alloys in the automotive industry. The study was conducted by researchers from Hyundai Motor's R&D Division and Hanyang University to develop materials that support carbon emission reduction, improved recyclability, and weight reduction in vehicle manufacturing.

The automotive industry increasingly demands sustainable materials that are both lightweight and high-performing. Low-density steel sheets, with densities reduced to approximately 6.5-7.1 g/cm³ through aluminum substitution, offer significant advantages. These materials combine high toughness and strength while exhibiting superplasticity—a phenomenon characterized by elongation rates exceeding 300%. This property enables the formation of large, geometrically complex sheet metal components in a single press operation, simplifying manufacturing processes by eliminating welding and reducing tooling costs. However, traditional superplastic steels require temperatures above half their melting point and extremely slow deformation rates (10^{-3}-10^{-5}/s), limiting industrial applicability.

The researchers designed three distinct Fe-Mn-Al-(-Si)-C steel compositions using thermodynamic calculations (TCFE) to predict equilibrium phase ratios and martensite transformation temperatures. Each composition was manufactured via vacuum melting, followed by heat treatment, hot rolling, cold rolling, and high-temperature tensile testing at various temperatures and strain rates. Microstructural analysis employed optical microscopy, scanning electron microscopy (SEM), electron backscatter diffraction (EBSD), and X-ray diffraction (XRD) to characterize phase composition and grain structure before and after testing.

Component System 1 (Fe-10Mn-4Al-0.2C, 5.5% weight reduction) demonstrated exceptional superplasticity with 536.2% elongation at 700°C and 10^{-3}/s strain rate. The duplex microstructure consisted of δ-ferrite, γ-austenite, and α-ferrite phases with grain sizes less than 1 μm. Notably, room-temperature tensile properties after high-temperature forming simulation showed yield strength of 710 MPa, ultimate tensile strength of 835 MPa, and 32% elongation—combining high strength with excellent formability.

Component System 2 (Fe-8Mn-3Al-1.3Si-0.2C, 5.3% weight reduction) achieved remarkable 990.6% elongation at 730°C and 10^{-3}/s, with superplasticity observed even at faster strain rates (2×10^{-2}/s) and lower temperatures (650°C). Reduced manganese content promoted martensite transformation, and silicon addition improved phase stability.

Component System 3 (Fe-12Mn-5Al-0.35C) showed lower superplastic performance with maximum 376% elongation, attributed to rapid austenite grain growth and insufficient grain boundary sliding activation at testing temperatures.

All compositions demonstrated that superplasticity operates primarily through grain boundary sliding (GBS) between refined α-ferrite and γ-austenite phases, independent of δ-ferrite presence or deformation. The critical factors for achieving superplasticity are refined grain structures and active grain boundary sliding at appropriate temperatures. The research confirms that Fe-Mn-Al-C lightweight steels are promising candidates for high-strength automotive components, maintaining excellent mechanical properties even after superplastic forming. Future work will focus on optimizing additional compositions to maximize weight reduction while enhancing superplastic elongation, with the ultimate goal of developing practical forming technologies for automotive applications.