論文 / 著書情報
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題目(和文)	オーステナイト系耐熱鋼のTCP Laves相による長時間クリープ強度に対する新概念
Title(English)	Novel Concept for Long-Term Creep Strengthening by TCP Laves Phase in Austenitic Heat Resistant Steels
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種別(和文)	論文要旨
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論 文 要 旨

THESIS SUMMARY

専攻： Department of	Metallurgy and Ceramics Science	専攻	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of (Engineering)
学生氏名： Student's Name	Imanuel Tarigan		指導教員（主）： Academic Advisor(main)	Prof. Masao Takeyama
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

In order to solve the energy crisis and at the same time protecting the environments, Japan needs more stable and reliable energy sources. One best solution receiving attention recently is the development of the advanced ultra-supercritical (A-USC) thermal power plant. For this application, there is strong demand of materials with the 10^5 h creep rupture strength at 973K is more than 100 MPa. Conventional ferritic and austenitic heat resistant steels cannot be used anymore under these conditions due to poor stability of metallic carbides in these steels. To challenge this problem, we have proposed a novel Fe-20Cr-30Ni-2Nb (at.%) austenitic heat resistant steel strengthened by intermetallics TCP (Topologically Closed-Packed) Laves phase and GCP (Geometrically Closed-Packed) Ni_3Nb-γ''. This steel shows superior creep rupture strength compared to the conventional austenitic heat resistant steels and promising to be used for the A-USC. Takeyama et. al. have qualitatively attributed the superiority to the precipitation of Laves phase at grain boundary. However the mechanism of how the grain boundary (GB) Laves phase improves the creep rupture strength has not yet been fully understood. Therefore, in this study, the role of GB Laves during creep has been quantitatively investigated in order to understand the mechanism.

In order to clearly identify the mechanism, we have intentionally controlled the precipitation of GB Laves phase in our steel, through small boron addition and aging treatment, and examine the changes in creep behavior. To analyze quantitatively the precipitation of GB Laves, the term area fraction (ρ), which is the total length of GB Laves phase divided by total length of the grain boundary, was used in this study. It has been found that increasing the precipitation of GB Laves phase further increases the creep rupture strength of the steel, without causing any ductility loss. It has also been revealed that the minimum creep rate of the steel decreases with increasing the area fraction of GB Laves according to equation: $\dot{\varepsilon} = \dot{\varepsilon}_0 (1-\rho)$, where $\dot{\varepsilon}_0$ is the minimum creep rate at ρ=0. The TEM (Transmission Electron Microscope) analysis of the specimen at minimum creep stage shows pile-up of perfect dislocations with burgers vector of **b** = 1/2<011> on GB Laves phase, while there is no apparent dislocations near the grain boundary. These results clearly indicate that GB Laves phase increases creep resistance and rupture strength of the steel by restricting the dislocation motion around grain boundary. We have proposed the strengthening mechanism as "*Grain Boundary Precipitation Strengthening*" (GBPS) mechanism

Although the GBPS mechanism can clearly describe the decrease of the creep rate up to the minimum creep stage, it seems to contradict with the increase of the creep rate at

the accelerating stage. For this reason, we have tried to examine the microstructure change in the accelerating stage to understand the phenomena and to clarify whether the GBPS mechanism also applies in this creep stage. The microstructures show a tendency that the ρ decreases with increasing macroscopic strain of the specimen. Further examinations by using EBSD (Electron Back-Scattering Diffraction) have shown that the grain boundary area uncovered by the Laves phase has higher misorientation and well-developed sub-grains compared the area near the GB Laves phase. These results strongly indicate that the creep deformation is not homogenously distributed within the grain, but preferentially occur at the uncovered grain boundary area. This is because, at high temperature, the grain boundary becomes the weakest site within the microstructures. The dislocation will either be annihilated or traverse to another grain when interacting with the grain boundary, resulting in much higher dislocation movement or creep rate at this area. We have proposed that this local creep rate, which has the fastest rate, will determine the overall creep rate of the bulk. By using this assumption, the creep acceleration can be explained by GBPS mechanism. Based on GBPS, the local deformed area near grain boundary without Laves have $\rho=0$, and thus the creep rate will be in order of magnitudes higher than that predicted using average ρ of the bulk, which is in agreement with the experimental results. It also explains why the steel with higher ρ has higher creep rupture strength and longer accelerating stage, that is due to the suppression of the local deformation by the GB Laves phase.

These studies have clearly identified and propose the GBPS mechanism by Laves phase in our model steel. This mechanism emphasizes the importance to control the microstructure at grain boundary to obtain superior heat resistant steels. It has been proven to be successful and effective for designing austenitic heat resistant steels for A-USC power plants, which is operated at 973 K. We believe that this strengthening mechanism could also be applied at higher temperature, providing that the same precipitation occurs. Based on this concept, we have challenged ourselves to design a new austenitic heat resistant steel to be used for 800°C power plant, which we termed it as Future-Advanced Ultra Super-Critical (FA-USC) power plant. However due to limited time of this study, it awaits further research to observe the results.