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Effect of a Hot Rolling Process on the Mechanical Behavior of 9Cr-1Mo Steel

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1. Introduction

Ferritic-martensitic steel (F/M steel) has been considered as the one of the main candidate cladding materials in the design of sodium-cooled fast reactor (SFR) in that it has higher thermal conductivity as well as dimensional stability under irradiation when compared as austenitic stainless steel. Optimization of the alloying element as well as manufacturing process has been carried out for the purpose of enhancing thermal creep property under the operation temperature. Among these, hot working process can be applied in the field of hot extrusion at the manufacture of the actual cladding where the hollow billet was formed into the intermediate product. In terms of these, it has been tried to enhance the high temperature mechanical property of the F/M steel by changing hot working temperature or the degree of the hot working rate to initiate the preferential precipitation of the MX particle at the metal matrix and the some works have been proposed [1,2]. However, lots of the works regarding the effect of the hot working process on the behavior of the F/M steel have yet to be gathered.

The objectives of the study are to analyze the effect of such a hot rolling process on the mechanical property of the F/M steel and to assess the hot rolling parameter in the field of a cladding manufacture.

2. Experimental Procedure

2.1. Material and hot rolling process

Material used in the study was modified 9Cr-1Mo steel (9Cr-1Mo-0.4Mn-0.3Si-0.2V-0.08Nb) where the small amounts of the V and Nb added into the conventional 9Cr-1Mo steel. Before the hot rolling, the modified 9Cr-1Mo block was heat-treated at the temperature 1200^{o}C for 30 minute to exclude the microstructural effect as well as dissolve all of the precipitation that remains at the as-received condition. Then the block was machined into the 15mm-thick block prior to the hot rolling. Hot rolling was conducted as the following conditions.

1) Specimen was hot rolled with the 60% reduction ratio at the given temperature right after the normalization at 1050^{o}C for 1 hour, then it was air-cooled. (abbreviated as process 1)
2) Specimen was hot rolled with the 60% reduction ratio at the given temperature right after the normalization at 1050^{o}C for 1 hour, then it was continuously annealed at the hot rolling temperature for 2 hours then it was air-cooled. (abbreviated as process 2)

Normalization without any hot rolling process followed by tempering at 750^{o}C for 2 hours was conducted for the comparison. Fig. 1 shows the schematic illustration for the hot rolling process in this study.

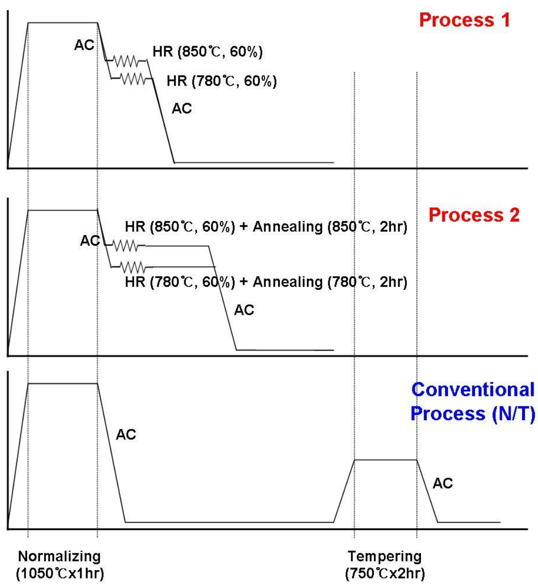

Fig. 1 Schematic illustration of the hot rolling process

2.2. Mechanical test

Mechanical test was performed over the heat-treated specimen for the purpose of evaluating their effect. Tensile test was performed in accordance with the ASTM E8 and E12 specification. Specimen was machined into the plate-type whose gauge length was 25mm. Tensile test was performed at both room temperature and 650^{o}C. Yield stress and elongation at rupture was measured through the stress-strain curve.

3. Results and Discussion

3.1. Result of the mechanical test

Fig. 2 shows the result of the 650°C yield stress and the elongation of the modified 9Cr-1Mo steel. Yield stress and elongation at 650°C of the specimen in process 1 were 485MPa and 14.4% when hot rolled at 780°C, which showed 42% increase in yield stress and 31% decrease in elongation when compared to the conventional process (normalizing-tempering condition). In the case specimen hot rolled at 850°C, the yield stress and the elongation were respectively 498MPa and 14.2%, which showed 43% increase in the yield stress and 31% decrease in the elongation when compared to the conventional process. In the process 2, where the continuous annealing was conducted right after the hot rolling, yield stress and elongation at 650°C were respectively 159MPa and 41.8% in 780°C hot rolled condition, whereas 375MPa and 17.4% in 850°C hot rolled condition. Introduction of the continuous annealing led to the change of the mechanical property that strength decreased to the value of 67% in 780°C and 25% in 850°C, whereas elongation increased to the value of 190% in 780°C and 22% in 850°C condition. When the annealing temperature decreased, the change was more significant.

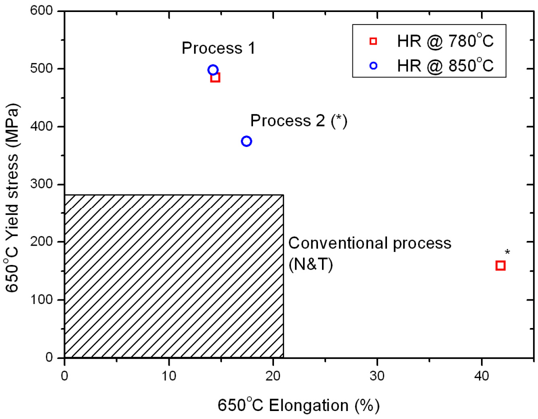

Fig. 2 Diagram of the mechanical strength and the ductility of the 9Cr-1Mo steel with the hot rolling process

3.2. Effect of the hot rolling process

In the process 1, where the hot rolling proceeds at the desired temperature as the specimen cooled, yield stress significantly increased when compared to the conventional process. Such may be attributed to the effect of the work hardening during the rolling. As the specimen was rolled, considerable amount of dislocation was piled up at the specimen matrix so that it induces hardening at the material caused by the dislocation entanglement. Since there has been little effect on the rolling temperature, this also implies that work hardening governs during the hot rolling stage regardless of the rolling temperature. Although strength is increased, ductility significantly reduced so that process 1 cannot be solely used in terms of the formablility during the manufacture of actual cladding. Additional heat treatment is needed to diminish such the work hardening. In the case of introduction of isothermal annealing after the hot rolling, such as process 2, portion of the work hardening was alleviated so that reduction of the strength as well as increase in the ductility observed when compared to the process 1. However, the effect of the annealing temperature was dominant in that strength of 850°C treated condition was higher than that of 780°C, whereas the ductility is reversed. 850°C is the temperature at which austenite phase is stable so that it makes the microstructure be martensite. On the other hand, 780°C is the temperature at which ferrite phase is stable so that considerable phase transform occurs during annealing to reduce the strength as well as increase the ductility.

4. Conclusions

Studies were carried out to investigate the effect of a hot rolling process on the mechanical property of F/M steel. Modified 9Cr-1Mo steels were hot-rolled at a temperature of either 780°C or 850°C right after normalization. Continuous annealing at the rolling temperature was performed and they were compared to the condition without a hot rolling process. Introduction of the hot rolling resulted in a work hardening so that the strength of the material increased. Continuous annealing at 780°C led to a phase transformation so that the strength of the material was significantly reduced. Study concluded that a hot rolling at 850°C followed by a continuous annealing could be tentatively applicable. Further study regarding the optimization of the hot rolling process is planned for the next step.

Acknowledgement

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