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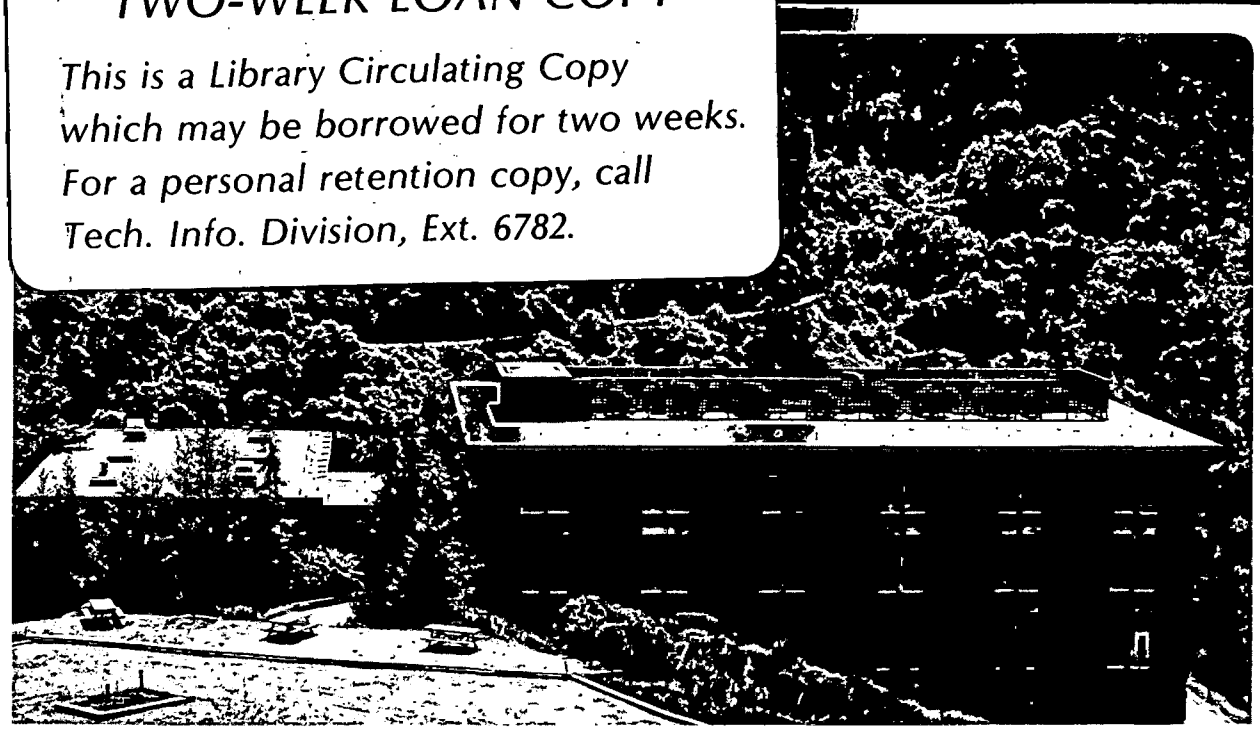

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THE INFLUENCE OF PROCESSING ON THE CRYOGENIC MECHANICAL PROPERTIES OF HIGH STRENGTH HIGH MANGANESE STAINLESS STEEL

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INTRODUCTION

New high strength structural steels have been required for the large superconducting magnets that will be used for the next step test facility for fusion reactor research. The new materials must have high yield strength accompanied with better toughness and better fatigue resistance compared with the conventional nitrogen-strengthened stainless steels such as AISI 304LN and 316LN that were used for the cases of the toroidal field coils for the Large Coil Project.

A number of new high manganese austenitic steels have been proposed for new cryogenic structural alloys since they can offer low cost, stable austenite and high strength.

The previous research [1] has shown that, in order to achieve superior cryogenic mechanical properties in the high manganese austenitic steels, the alloy should be kept free of residual δ-ferrite and the carbon content should be held to a low value. Then one alloy of nominal composition 18Mn-5Ni-16Cr-0.02C-0.216N alloy was selected from the wide range of high manganese austenitic stainless steels. The present research was conducted to clarify the influence of the processing (hot rolling and cold rolling conditions) on the cryogenic mechanical properties of this alloy.

* On leave from Kobe Steel Ltd., Japan

Table 1. 18Mn-5Ni-16Cr alloy composition (wt.%).

Mn	Ni	Cr	Si	P	S	C	N	C+N
17.98	4.96	16.26	0.53	0.004	0.010	0.024	0.216	0.240

EXPERIMENTAL PROCEDURE

A 300 kg ingot of nominal composition 18Mn-5Ni-16Cr-0.02C-0.22N was prepared by vacuum-induction melting. The ingot was hot-forged to 80 mm thickness plate and then hot-rolled in three hot rolling conditions. The hot rolling conditions were changed by varing the soaking temperature of the plates (1250, 1200 and 1150°C). Each forged plate soaked at each temperature for one hour was then hot-rolled to 30 mm thickness plate in the same rolling pass schedule. One part of the plate hot-rolled from 1250°C was solution-treated at 1050°C for 30 min followed by water quenching. The plates that were solution-treated and as-hot-rolled from 1250°C were cold-rolled to 21 mm thickness plate (30% rolling reduction) at room temperature in order to investigate the effect of cold rolling.

Tensile and compact tension (CT) specimens were prepared from these plates. The measured alloy compositions are given in Table 1. Tensile specimen dimensions were 6.35 mm diameter and 25.4 mm gauge length. CT specimen dimensions were w=50.8 mm and B=25.4 mm (B=19 mm for cold rolled plates). Specimen direction (load direction) was parallel to the plate rolling direction. Tensile, fracture toughness (J-integral) and fatigue, tests were carried out using an Instron servo-hydraulic machine and cryostat. The J_{IC} values were obtained by compliance method, and the fracture toughness values (K_{IC}) were calculated from the following equation.

$$K_{IC} = J_{IC}E/(1 - \nu^2)$$

where E is Young's modulus, ν is Poisson's ratio. The fatigue tests were run at 10 Hz in load control (R=0.125) using a sinusoidal tension stress wave form. After testing, the fracture surfaces were investigated by scanning electron microscope.

RESULTS AND DISCUSSION

Tensile Properties at 4K

Tensile properties at 4K of all specimens are given in Figure 1. The yield and tensile strength increase with decreasing hot rolling

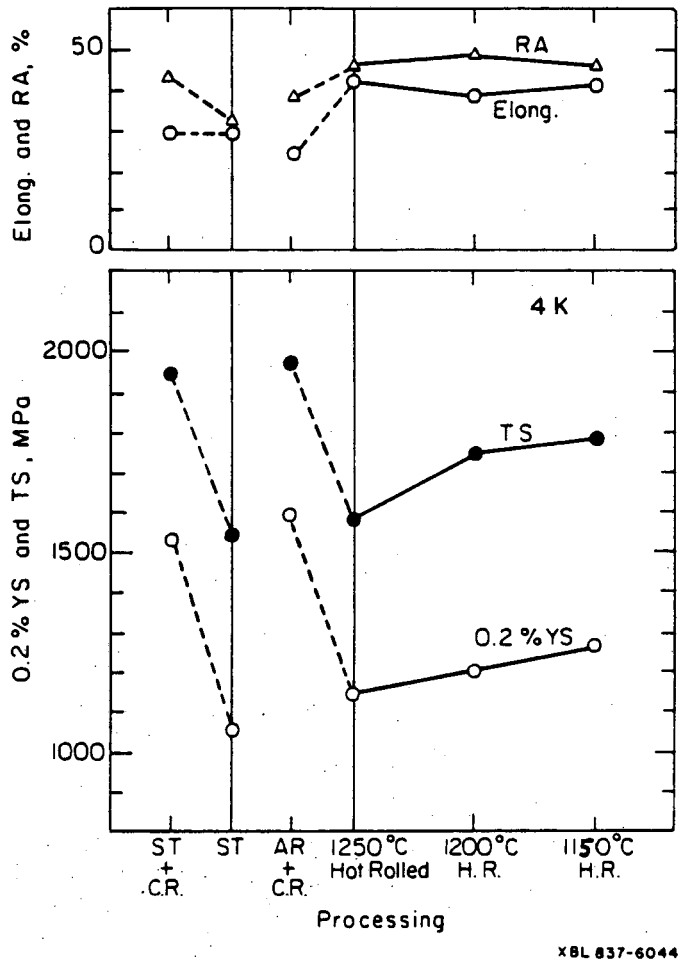

Fig. 1. The effect of processing on the tensile properties of 18Mn-5Ni-16Cr-0.02C-0.22N alloy at 4K.

temperature. The high strength of more than 1200 MPa can be obtained by low temperature hot rolling. The ductility (total elongation or reduction of area) are almost the same among the three hot rolling conditions. These as-rolled plate specimens show the large work hardening rate and relatively large uniform elongation but small local necking. The solution-treated plate shows lower strength and ductility than the as-rolled plate. Especially the local necking of the solution-treated plate specimen was very small at the fractured position.

Thirty percent cold rolling at room temperature leads to the increase in the strength of more than 400 MPa at 4K. Decrease in the ductility was observed in the hot-rolled plus cold rolled plate, but the decrease in the reduction of the area was small compared with the total elongation. Moreover, typical improvement in the reduction of the area was observed in the solution-treated plus cold-rolled plate. Both fractured specimens showed clear local necking at the fractured

position. Ten to twenty percent of the ε phase were found in the fractured specimens of the as-rolled and solution-treated plates. The formation of the ε phase during deformation raised the work hardening rate [4] and, accordingly, restricted the local necking. The formation of the ε phase was suppressed in the fractured specimens of the hot-rolled plus cold-rolled and the solution-treated plus cold-rolled plates. Dislocations that were introduced by cold rolling at room temperature supposedly suppressed the formation of the ε phase, then reduced the work hardening rate and enhanced local necking.

The yield strength is plotted as a function of reciprocal root of the average grain size ($d^{-1/2}$) in Figure 2. The yield strength of the as-rolled plates obeys the Hall-Petch relation like most common fcc metals. Therefore, increase in the strength with decreasing the hot-rolling temperature is mainly due to the grain refinement. The yield strength of the solution-treated plate is lower than the above straight line. It is due to the difference of the interstitial state (mainly nitrogen state), because the yield strength of this kind of alloy is very sensitive to the interstitial content and the state [1].

Fracture Toughness at 4K

Fracture toughness $K_{IC}(J)$ that was calculated from the J_{IC} value is also plotted as a function of the reciprocal root of the average grain size. The inverse relationship of K_{IC} and $d^{-1/2}$ was

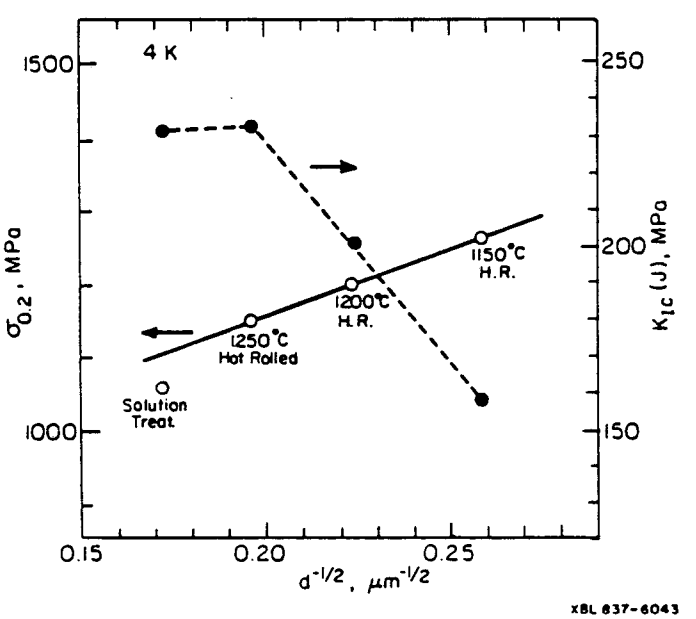

Fig. 2. The yield strength (σ0.2) and the fracture toughness as a function of reciprocal root of average grain size ($d^{-1/2}$) at 4K.

obtained for the as-rolled plate data. K_{IC} decreases rapidly with decreasing the grain size. Since the inverse relationship of K_{IC} and the yield strength is well known for the various fracture toughness data, K_{IC} is again plotted as a function of the yield strength in Figure 3. The data for the cold-rolled plates are also given in Figure 3. The linear relationship of the fracture toughness and the yield strength has been reported in reference [2] and is also given in Figure 3. Although a new material shows a better combination of unrecrystallized large grains in the fine grain matrix, but any abnormal fracture was not observed by the fractographic observation. The relatively large dimple patterns accompanied with a lot of secondary cracks were observed on the fracture surface of the high temperature hot-rolled plate (1250°C). Dimple patterns became flatter and the number of secondary cracks decreases with decreasing the hot-rolling temperature. The grain refinement clearly deteriorates the toughness in this austenitic alloy. Grain refinement is effective for ferritic steels which indicates clear ductile-brittle transition to lower the ductile-brittle transition temperature, but it has been reported that fine grain does not have any effect in increasing the absorption energy of the ductile fracture [5].

The relationship for the fracture toughness and strength of the cold-rolled plates are also included in Figure 3. Although the toughness decreases with increasing the strength, this slope for cold-rolled plates was nearly the same as that reported for 304N alloy [3].

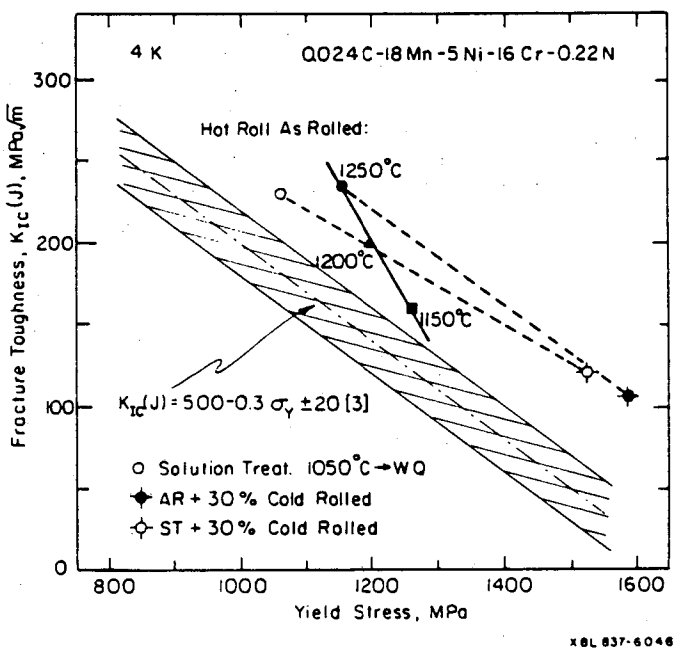

Fig. 3. The relationship between the fracture toughness and the yield strength at 4K.

A slight improvement was observed for the solution-treated plate. This improvement might be attributed to the increase in the ductility. So small cold rolling is an effective way to increase the strength without the rapid deterioration of the toughness.

Fatigue Crack Growth Rate at 77K

Fatigue crack growth rate, da/dN, at 77K is plotted as a function of stress intensity range ΔK in Figures 4 and 5. The data previously reported for 304LN and 304 [3] are given in both figures. These figures show that the fatigue crack growth rates of this alloy are substantially below that of 304LN alloy but slightly higher than that reported for 304 steel. There is no big difference among the three hot-rolling conditions as shown in Figure 4. The failure mode was also nearly the same. So the grain refinement does not affect the fatigue crack growth rates at the intermediate ΔK.

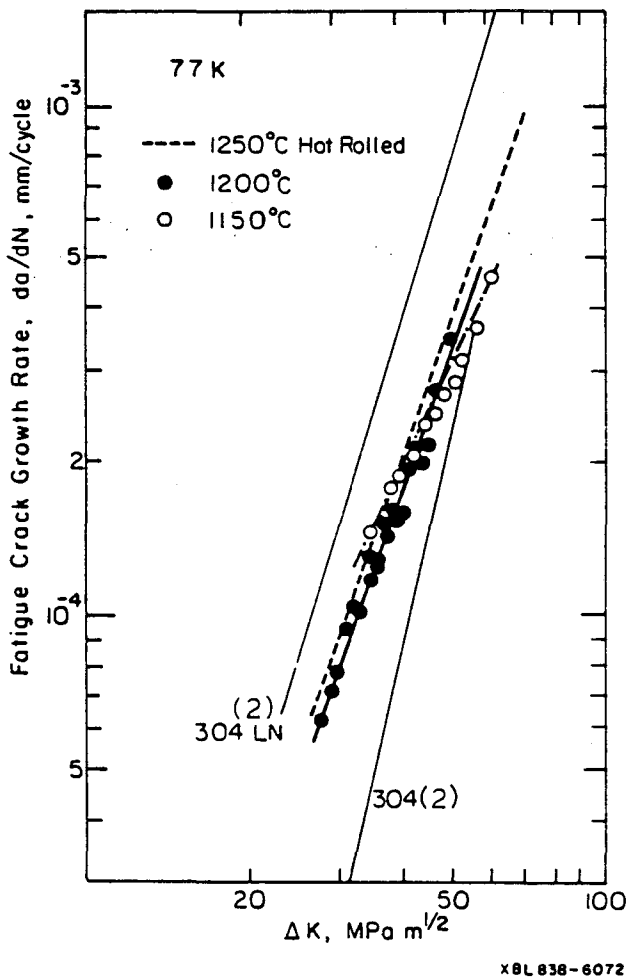

Fig. 4. The effect of hot-rolling conditions on the fatigue crack growth rates at 77K.

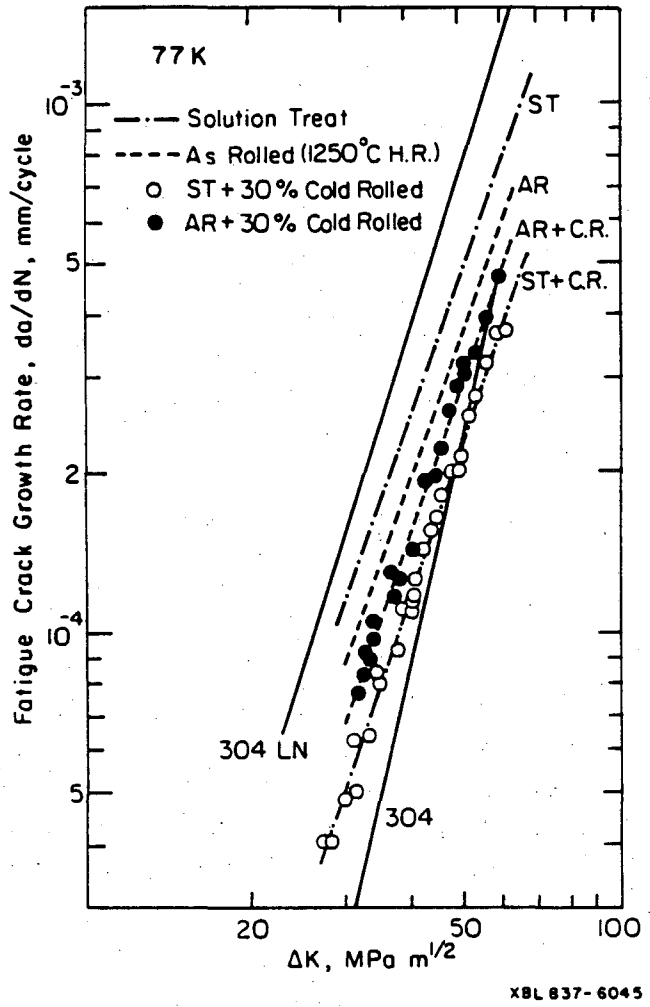

Fig. 5. The effect of cold rolling on the fatigue crack growth rates at 77K.

Figure 5 shows the effect of cold rolling. Fatigue crack growth rates of cold-rolled plates are lower than those of as-rolled and solution-treated plates. Especially solution-treated plate showed significant improvement on the fatigue crack growth rates by cold rolling. Although the ductile striations are poorly defined and crystallographic flat facet are sometimes visible on the fracture surface of the solution-treated plate specimen, the ductile striations became clearly defined and flat facets disappeared on the fracture surface of the cold-rolled plate specimen. Forty percent and thirty-eight percent of the ε phase were found on the fatigue fracture surfaces of the as-rolled and the solution-treated plates, respectively. The ε phases decreased to 26% and 20% on the fracture surfaces of the cold-rolled plates. Therefore the improvement of fatigue resistance might be attributed to the improvement of ductility through suppression of the formation of the ε phase.

CONCLUSIONS

The influence of the hot rolling condition and cold rolling on the mechanical properties of a nitrogen-strengthened high manganese steel of nominal composition 18Mn-5Ni-16Cr-0.02C-0.22N were investigated. The results include:

1. Grain refinement by low temperature hot rolling raises the strength of the alloy but decreases the toughness rapidly.

2. Cold rolling at room temperature is an effective way to raise the strength without rapid deterioration of the toughness.

3. Changing the hot rolling condition did not affect the fatigue crack growth rates, but the decrease in the fatigue crack growth rates was observed for cold-rolled plates. This improvement of the fatigue resistance might be attributed to the improvement of the ductility through the suppression of the formation of the ε phase.

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REFERENCES

1. R. Ogawa and J. W. Morris, Jr., Proc. of the International Cryogenic Materials Conf., Kobe, Japan, 1982, p. 124.
2. D. T. Reed and R. P. Reed, Materials Studies for Magnetic Fusion Energy applications at Low temperatures-II NBSIR79-1609. National Bureau of Standards, Boulder, COLO, 1979, p. 81.
3. R. L. Tobler, D. T. Reed and R. P. Reed, Materials Studies for Magnetic Fusion Energy Applications at Low Temperatures-IV NBSIR81-1645, National Bureau of Standards, COLO, 1981, p. 37.
4. A. Soto, K. Soma and T. Mori, Acta Metall. 30:10:1901 (1983)
5. S. Jin, S. K. Hwang and J. W. Morris, Jr., Met. Trans. A, 6A, 1721 (1975).

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