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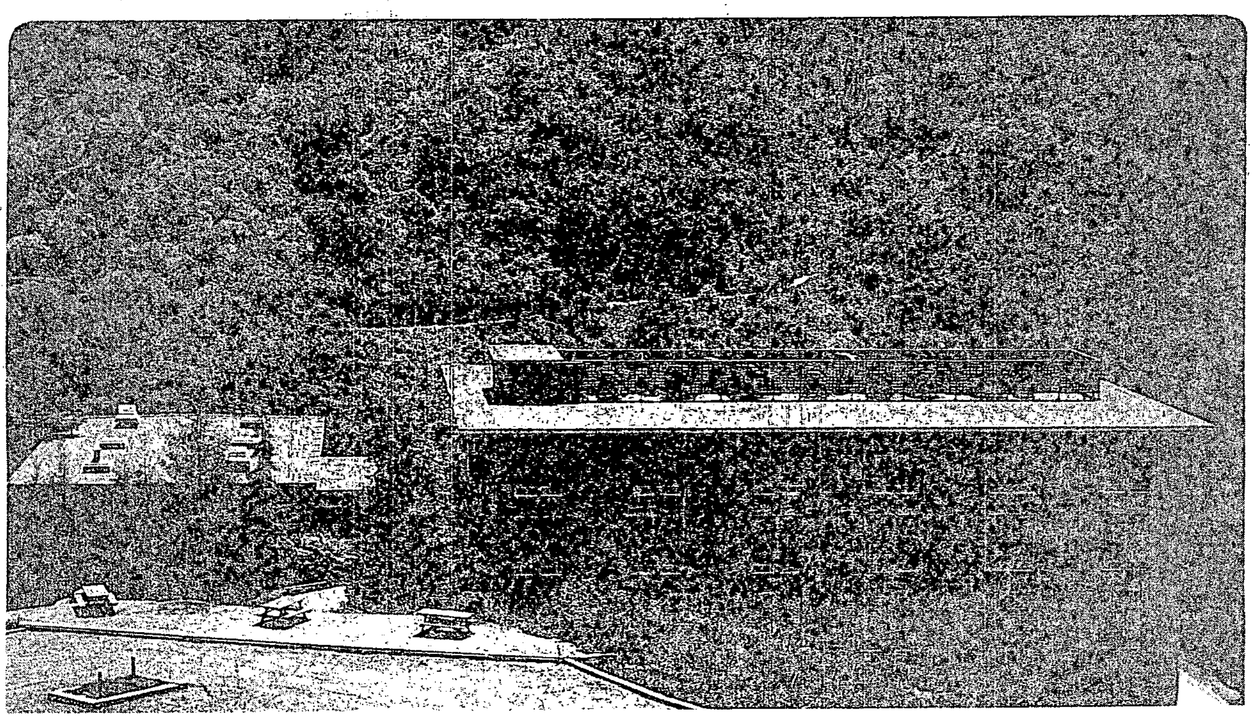

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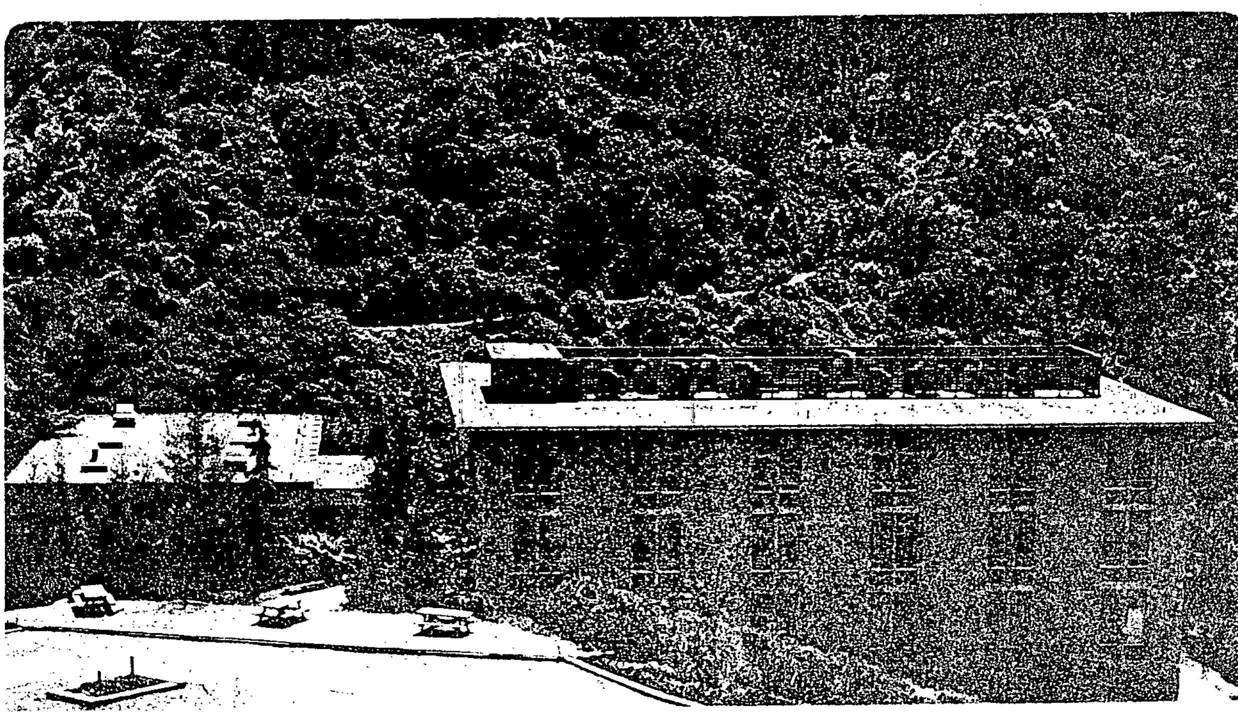

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DISCLAIMER

THE INFLUENCE OF ALLOY COMPOSITION ON THE CRYOGENIC MECHANICAL PROPERTIES OF AISI 200 GRADE HIGH MANGANESE AUSTENITIC STEELS

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ABSTRACT

Research on the effect of composition on the cryogenic mechanical properties of high-Mn austenitic steels showed that both the yield strength and change of strength with alloy processing increased significantly with increasing interstitial content. Alloy toughness deteriorated if carbon content was raised to 0.1% or higher or if δ-ferrite was retained in the as-cooled alloy. On the basis of these investigations an alloy of nominal composition 18Mn-5Ni-16Cr-0.024C-0.22N was made and tested at 4K. Both its strength-toughness characteristic and fatigue crack growth properties compared favorably to those of 304LN and 304N cryogenic steels.

INTRODUCTION

The development of high field superconducting magnets, particularly for use in magnetic fusion reactors, has created a need for new structural alloys that combine high strength and toughness at 4K with low cost and dependable performance in thick sections. To satisfy this need, a number of laboratories have been investigating the potential of high manganese austenitic steels [1,2,3]. The classic high manganese austenitic steels have been standardized in the AISI 200 series, in which the manganese is used principally to increase nitrogen solubility and to achieve higher strength [4]. These alloys typically have poor fracture toughness at cryogenic temperatures, but recent research [3] has shown that promising cryogenic properties can be obtained in a modified AISI 205 steel having nominal composition 18Mn-5Ni-(14-16)Cr-0.03C-0.26N. The present research was conducted to explore alloy compositions around this nominal value, and to select a promising composition for detailed cryogenic mechanical property tests.

EXPERIMENTAL PROCEDURE

The experimental alloys were prepared by vacuum-induction melting a variety of compositions about the base alloy composition 18Mn-5Ni-16Cr-0.03C-0.26N. The alloy compositions are given in Table I. The ingots were forged to 50 or 75mm thick plates and then hot rolled at 1100°C to 15 or 30mm thickness. Cryogenic tensile and Charpy impact properties were measured in three conditions: as-hot rolled, solution treated (1050°C for 30 min + water quench) and solution treated and aged (660°C, 45 min + air cooled). The properties were determined in the rolling direction of the plate. Single specimen J-integral tests on a selected alloy were performed at 77K and 4K using longitudinal compact tension specimens (b=25.4mm, W=50.8mm, a/W~0.65). Fatigue crack growth rates were measured at 4K using a similar compact tension specimen, a load ratio of 0.12, and a frequency of 10 Hz. The crack length was determined by the compliance method.

RESULTS AND DISCUSSION

The 4K yield strengths of the alloys was almost insensitive to the composition of substitutional species over the range tested, but varied strongly with the interstitial content as shown in Figure 1. As the total interstitial content increased to above 0.25 wt.% the yield strength increased significantly, as did the sensitivity of the yield strength to the processing conditions. Nitrogen is clearly more effective than carbon in strengthening the alloyµ the data presented in Figure 1 show that the strength decreases with increasing carbon fraction at a given total interstitial content.

The relation between Charpy V-notch impact energy and yield strength at 77K is plotted in Figure 2. As expected, the Charpy impact energy tends to decrease with yield strength. But beyond this general trend, the data can be divided into three groups depending on metallurgical characteristics. The first group includes alloys that contain residual δ-ferrite, as evidenced by high magnetic permeability. These include high manganese (28Mn-5Ni-16Cr), high Cr (18Cr-5Ni-18Cr) and low Ni (18Mn-1Ni-16Cr) alloys. These alloys, which are labelled γ+δ+N the figure have low toughness in the as-rolled or solution-treated condition, and show a dramatic deterioration in impact toughness when given a further aging treatment. The second group of alloys contains relatively high carbon additions (0.10-0.16C) and is designated α+C+N in the figure. These alloys also show relatively low toughness in the as-rolled or solution-treated condition, and also lose toughness on aging. The final group of alloys are low in carbon and do not contain δ-ferrite. These alloys have high impact toughness at 77K and do not lose toughness on subsequent aging, which suggests that they may show good welding characteristics. The strength-toughness properties of these alloys are nearly independent of the precise content of the substitutional alloying species.

In selecting a high manganese austenitic alloy for cryogenic use it is desirable that the alloy have good cryogenic mechanical properties, that the properties be relatively insensitive to processing to optimize alloy reliability and reproducability, and that the properties be relatively unaffected by heat treatment, to minimize problems in the heat-affected zone after welding. The data presented above suggests that such an alloy should be free of δ-ferrite, have a total interstitial content below about 0.25 wt.%, and have a carbon content which is low relative to that of nitrogen. All three of these criteria are satisfied by an alloy of nominal composition 18Mn-5Ni-16Cr-0.22N-0.024C. An alloy of this nominal composition, a small Si addition for deoxidation, was melted and prepared for detailed property measurements at 4K. The actual composition of the experimental material was 18.0Mn-5.0Ni-16.3Cr-0.53Si-0.22N-0.024C-0.01S-0.004P.

J-integral tests were conducted on the experimental alloy in both the as-rolled and solution-treated conditions at 77K and 4K. The 77K data were invalid because of the exceptionally high J-integral values. The valid results obtained at 4K were J_{Ic}=245KJ/m^2 for solution-treated condition and J_{Ic}=280KJ/m^2 in the as-rolled condition. The plane strain fracture toughness values (K_{Ic}) estimated from these values are plotted together with the corresponding 4K yield strengths in Figure 3. The results are compared against the strength-toughness characteristic for 304LN and 304N steels at 4K as reported in References 5 and 6. It is clear from the figure that the high Mn alloy has a 4K strength-toughness combination superior to that of 304Ln or 304N steels. The fatigue crack growth rate data of the experimental alloy at 4K is given in the Paris plot contained in Figure 4 and compared with the crack growth rate data for 304 and 304LN steels reported in Reference 5. The crack growth rate of the experimental alloy is relatively insensitive to processing, though the as-rolled condition shows a slightly smaller fatigue crack growth rate at higher ΔK value. The fatigue crack growth rates over the whole range tested are substantially below the reported data for 304LN, though they are slightly higher for the crack growth rates reported for 304. Fatigue crack growth rates were also measured at77K and are very nearly the same except at the highest ΔK values.

CONCLUSION

We conclude that a very promising combination of yield strength, fracture toughness, and fatigue resistance at 4K can be obtained with modified AISI 205 high manganese austenitic steels. To achieve superior cryogenic mechanical properties the alloy should be kept free of residual δ-ferrite and the carbon content should be held to a low value. The alloy's strength may then be increased by adding nitrogen though a low total interstitial content may be useful in suppressing the dependence of the mechanical properties on processing conditions.

ACKNOWLEDGMENTS

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TABLE 1

MATERIALS	
Base Alloy	28%Mn-5%Ni-16%Cr-0.03%C-0.26%N
Effect of Mn	(15,18,20,22,28%)Mn-5%Ni-16%CR-0.03%C-0.25%N
Effect of Ni	18%Mn-(1,3,5,7%)Ni-16%Cr-0.03%C-0.25%N
Effect of Cr	18,22%Mn-4,5%Ni-(12,14,16,18%)Cr-0.03%C-0.25%N
Effect of C	18%Mn-5%Ni-16%Cr-0.10%C-0.177%N -0.16%C-0.122%N

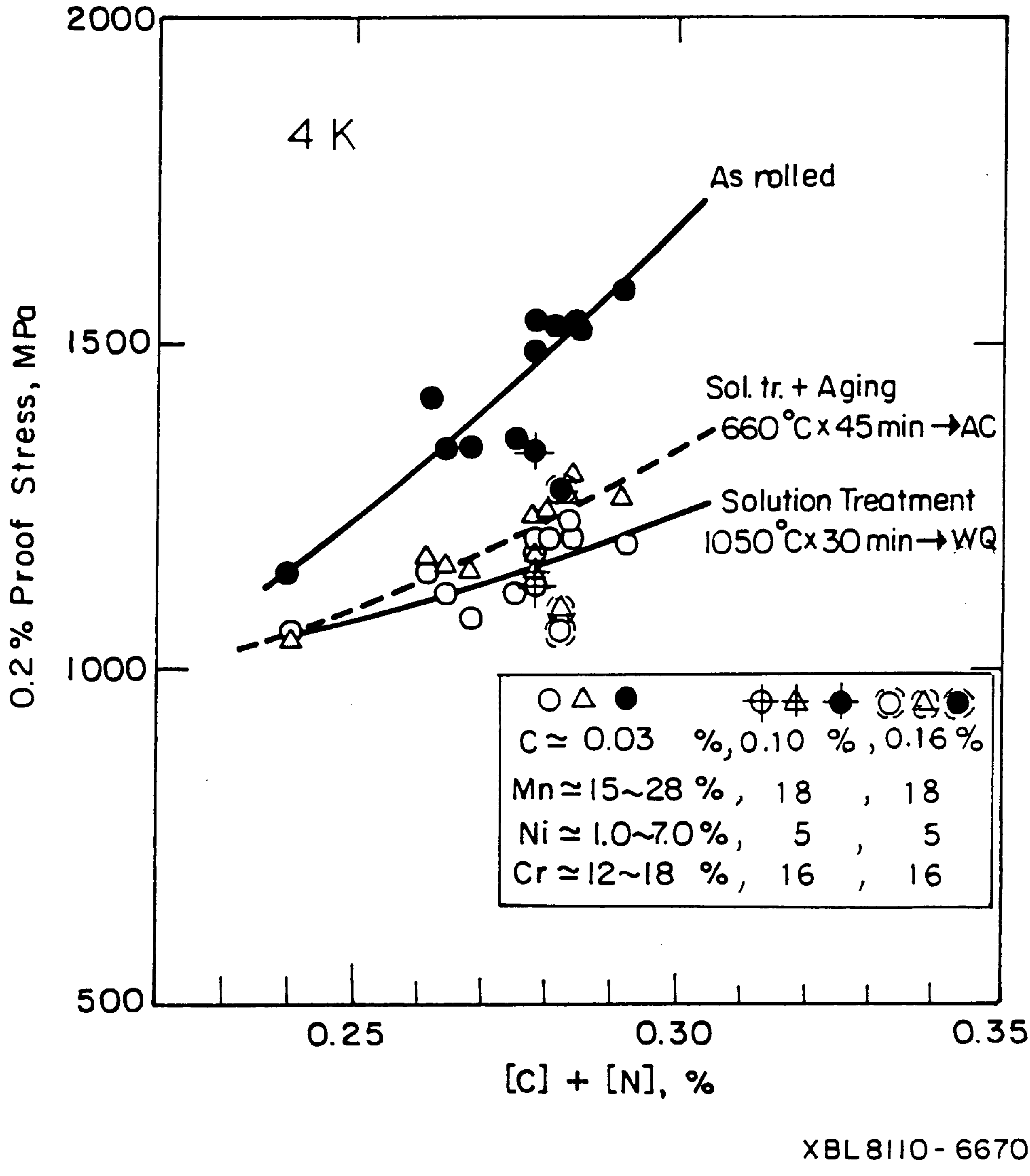

Figure 1. Dependence of the yield stress on interstitial content.

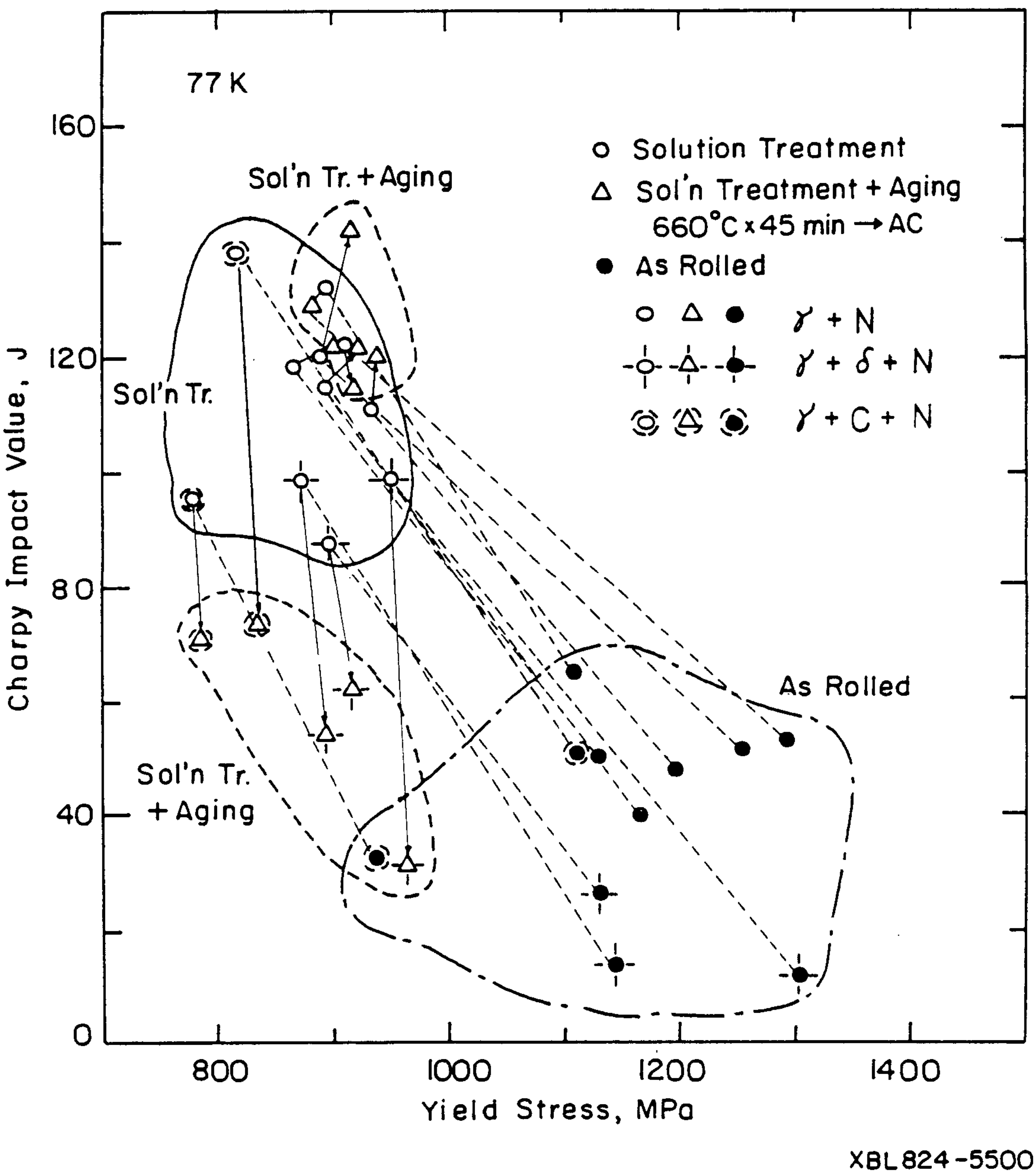

Figure 2. Relationship between Charpy impact energy and yield stress at 77K.

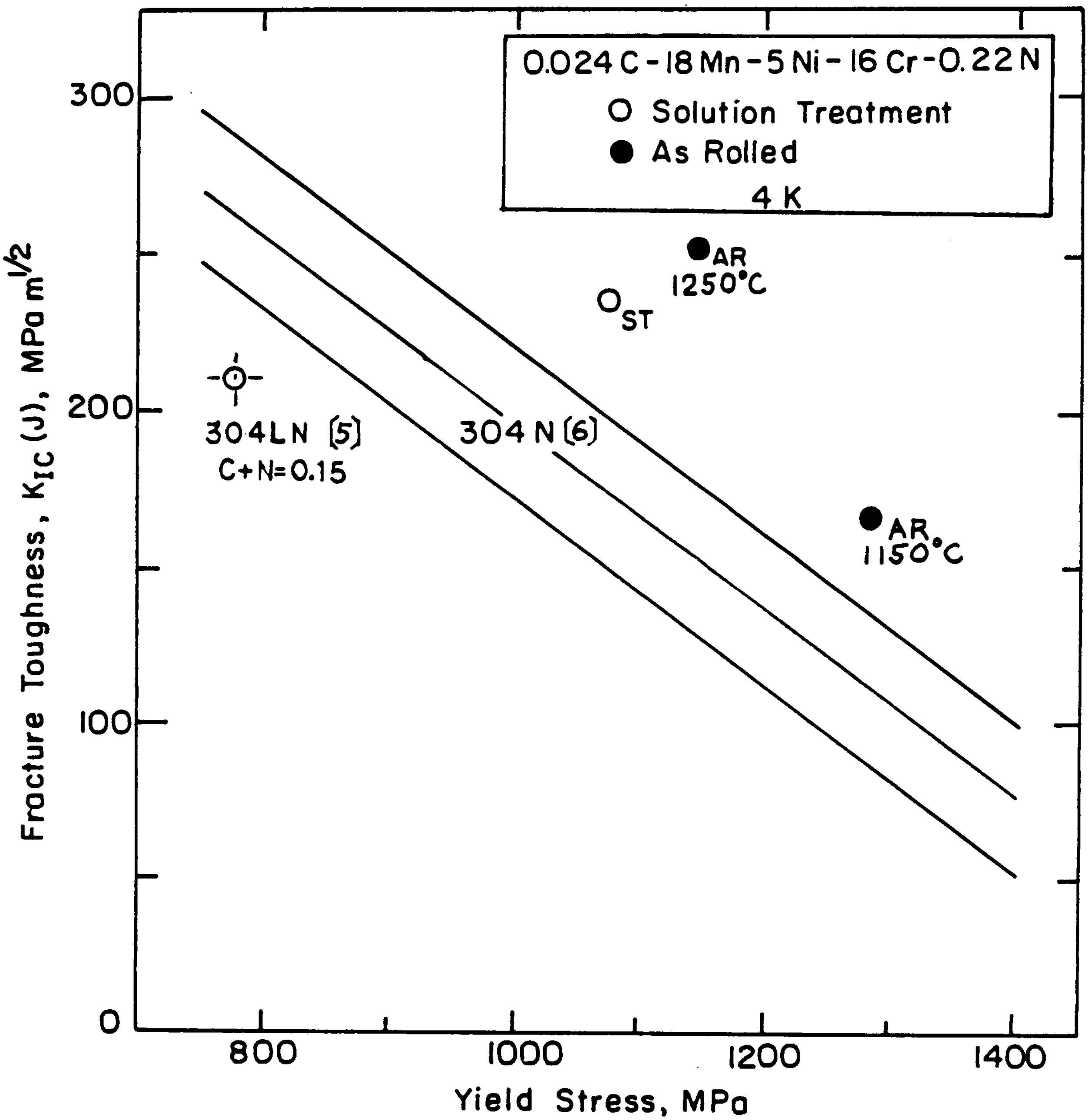

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Figure 3. Relationship between fracture toughness and yield stress of the alloy at 4K.

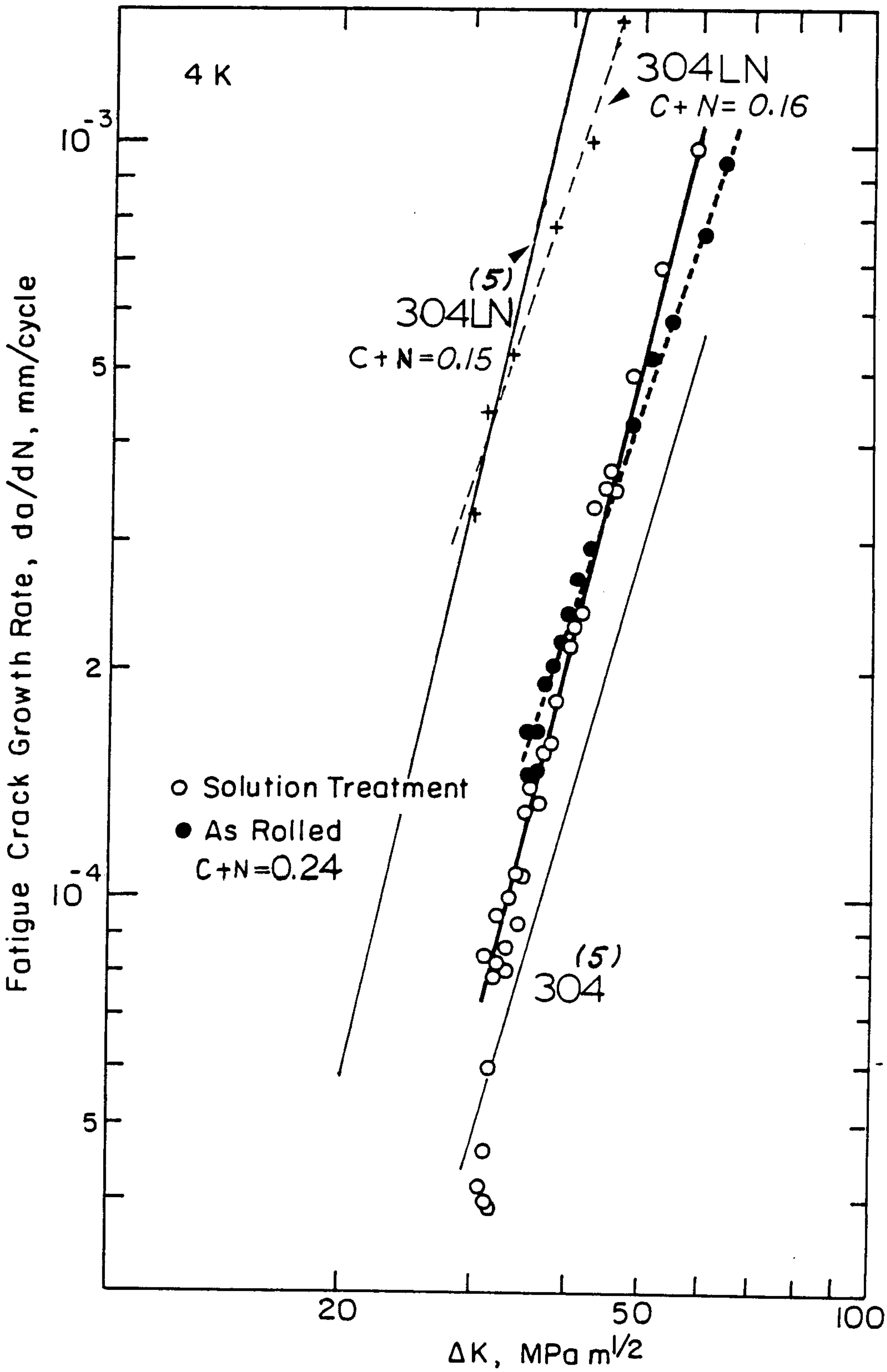

Figure 4. Fatigue crack growth rate of 0.024C-18Mn-5Ni-16Cr-0.22N alloy.

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