THE INFLUENCE OF STRUCTURAL PARAMETERS ON CRACK PROPAGATION IN HIGH-STRENGTH STEELS.

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The influence of aging temperature on fatigue crack growth rate J_{IO} and of precipitation hardened steels of the type X3CrNiCuNb 15 5 and X5NiCrTi 26 15 is discussed. For crack growth rates above 10^{-3}mm/cycle a slight influence on crack propogation of grain size and sulfur content are observed after aging above the maximum of strength.

1. INTRODUCTION

The crack-propogation behaviour under static (fracture toughness) and cyclic stress (cyclic strength) is an important mechanical property of materials. The enhancement of fracture toughness and the reduction of the velocity of crack propogation is especially important in the case of precipitation-hardened steels. Only then full advantage can be taken of the high strength values.

The crack-propagation behaviour of a steel is influenced by its plastic properties (yield stress, hardening, ductility etc.).On the other hand, these attributes are dependent on the structure under consideration (matrix, inclusions, grain size, grain boundaries etc.) (1).
In the following some results of fracture-mechanical investigations on precipitation-hardened steels will be reported. The influence of heat treatment and of some structural parameters on fracture toughness and crack propagation are presented.

2. TESTING MATERIALS AND EXPERIMENTAL PROCEDURES.

The investigations were carried out on stainless precipitation-hardened steels of the type X3CrNiCuNb 15 5 and X5NiCrTi 26 15. The chemical composition is given in table 1.

The martensitic steel X3CrNiCuNb 15 5 was molten using electro slag remelting procedure. This steel exhibits excellent toughness properties in the logitudinal and the transversal direction as well. The austenitic steel X5NiCrTi 26 15, also produced by electro slag remelting shows a high toughness and fracture toughness besides its appreciable strength at elevated temperature.

In case of tough alloys the determination of the K_{IC}-value can be carried out only in a hard way in accordence to the methods of linear-elastic fracture mechanics. Therefore the fracture-mechanical investigations were carried out using the J-integral introduced by Rice (2). The determination of the critical J-values was carried out on three-point bending specimens according to the multispecimen-technique presented in (3). The J-integral method permits an investigation of the fracture behaviour using small specimens even in the case of elastic-plastic material behaviour. The critical J is determined as J_{IO} at the start of crack propagation. Furthermore, it's possible to obtain valid K_{IC}-values by calculating K_{IO} from J_{IO}.
The growth rate of fatigue cracks was determined using CT-specimens according to ASTM E647 (4).

3. EXPERIMENTAL RESULTS

3.1 Fracture toughness

Heat treetment and development of structure have essential influence on fracture toughness.

In fig. 1 the dependence of the mechanical properties on the aging temperature is presented for the steel X5NiCrTi 25 15. After solution at 950^{o} C and aging at 700^{o} C annealing the steel possesses a maximum of strength. If the aging temperature

decrease to lower temperature the tensile strength and off-set strain also decrease.
The fracture strain increases before the maximum of trength.

In fig. 2 the J_{IO}-values are presented as a function of the aging temperature. At an aging temperature of 750° C the J-values show a minimum at 200 Nmm^{-1}. This corresponds to a K_{IO}-values of 6680 $Nmm^{-3/2}$. At higher or lower aging temperature the value of the J-integral increases noticibly. The minimum of fracture toughness coincides with the temperature range in which, storting from the grain boundaries, a rod-or plate-like hexagonal $Ni_3Ti(\eta)$ phase develops, with grows at the expense of dissoloing γ'-particles. As shown in (5) the toughness decreases.

The heat treatment of steel X5NiCrTi 26 15 should be performed in such a way that the η-phase does not appear. To obtain optimum values of fracture toughness the aging temperature should not exceed 730° C. The highest J-values are reached when aging takes place just in front of the maximum of strength.

In the case of the steel X3CrNiCuNb 15 5 the dependence of the mechanical properties on the aging temperature can be seen in fig. 3. After solution annealing at 1040° C the maximum of the off-set strain is reached at an aging temperature of 480° C. At higher or lower aging temperature the 0,2 %-off-set strain decreases and the fracture strain increases shightly.

Ater aging for maximum strength a minimum of fracture toughness of J_{IO}= 22 Nmm^{-1} (K_{IO}= 2180 $Nmm^{-3/2}$) was observed at room temperature (fig. 4). Aging above the strength maxima produced J_{IO}-values which were essentially higher than in the unhardened state. At a testing temperature of -50° C the J_{IO}-values are only slightly lower than those at room temperature. For the steel X5NiCrTi 26 15, which has a higher Chromium-content than the alloy X3CrNiCuNb 15 5, the same dependence of fracture toughness on aging temperature was observed.

3.2 Crack propagation on the steel X3CrNiCuNb 15 5.

The crack-growth rate was determined as a function of the stress intensity factor range. In fig. 5 the influence of aging temperature on fatigue crack growth is presented. The crack-growth rate reaches its maximum after annealing for maximum strength. With decreasing strength the crack-growth rate decreases for annealing below the maximum. The lowest crack growth rates, however, occurs after aging above the maximum strength.

For the state of lowest crack-growth rate, which occurs after aging above the maximum strength, the influence of grain size on fatigue crack growth was investigated.
The grain size was reduced from 0-00 (according ASTM E112-63) to 5-6.

It can be seen from fig. 6 that no influence of grain size on crack growth could be found for cyclic loading. The differences in crack growth rate was within the limits of experimental accurancy. Only at high stress intensity factor ranges ΔK a small influence of grain size is observed. The high toughness of the CrNi-martensite causes the development of a transcrystalline ductile fatigue fracture. With increasing ΔK, secondary cracks occur between the martensitic plates. Regardless of grain size this leads to a low macroscopic crack growth rate.
For the steel X3CrNiCuNb 15 5 a reduction of the sulfur content form 0,012 to 0,003 % causes a considerable increase of the impact value (Fig.7).
The influence of sulfides on the propogation of fatigue cracks was investigated with samples of 0,0004 and 0,012 % S. At low crack-growth rates is no effect of sulfidic inclusions in the crack propagation (Fig.8). Only at higher crack-growth rates the inclusions enhance the crack velocity. An extrem reduction of the sulfur content does not improve the crack-growth rate in cyclic loading.

LITERATUR:

1. Schwalbe, K.H., 1980, Bruchmechanik metallischer Werkstoffe, Carl Hanser Verlag, München Wien.
2. Rice, J.R., 1968, Trans, ASME, J.Appl.Mech., 379-386.
3. Clarke G.A., Andrews W.R., Belgley J.A. u.a., J.Testing and Evaluation 7, 49.
4. ASTM E647-78T, 1978, Hannual Book of ASTM Standards, Part 10.
5. Schubert F., Horn E., 1974, Thyssen Technische Berichte 6,43-52.
6. Rack J., Kalish D., 1974, Metallurgical Transactions 5, 1595-1605

Table 1: Chemical Composition of the Alloys

Material	C	Si	Mn	Cr	Mo	Ni	Cu	V	Ti	Al
X5NiCrTi26 15	0,05	0,6	1,4	15,0	1,3	25,3	-	0,3	2,1	0,23
X3CrNiCuNb15 5	0,03	0,3	0,8	14,5	-	4,5	3,3	-	-	-

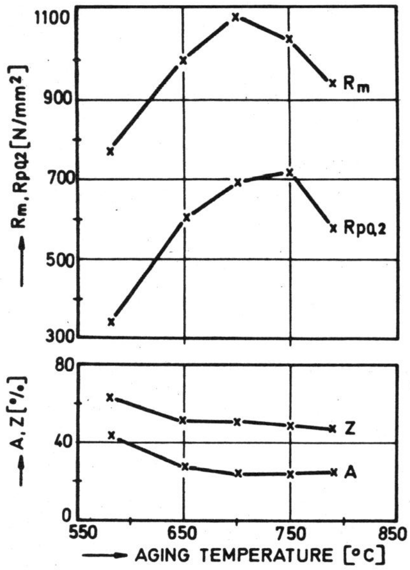

Fig. 1:X5NiCrTi26 15-Aging Diag. Mechan.Parameters,Longidutinal.

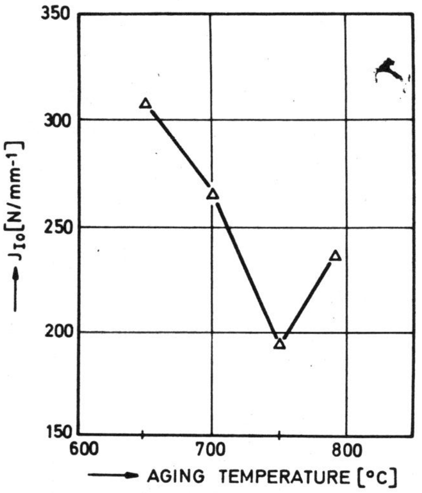

Fig. 2:X5NiCrTi26 15-Influence of Aging Temp. on J_{IO}

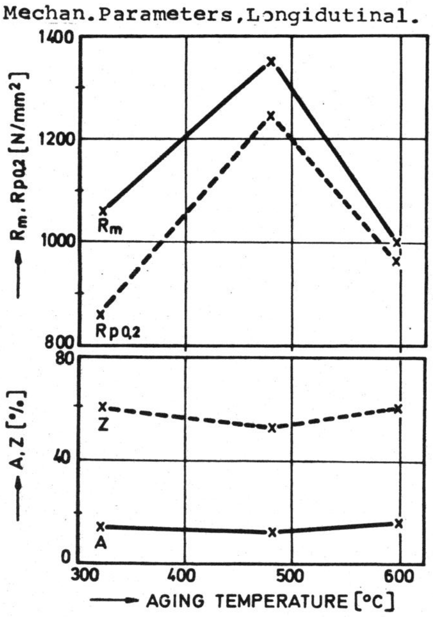

Fig. 3:X3CrNiCuNb155-Aging Diagr. Mechan.Parameter,longidutinal

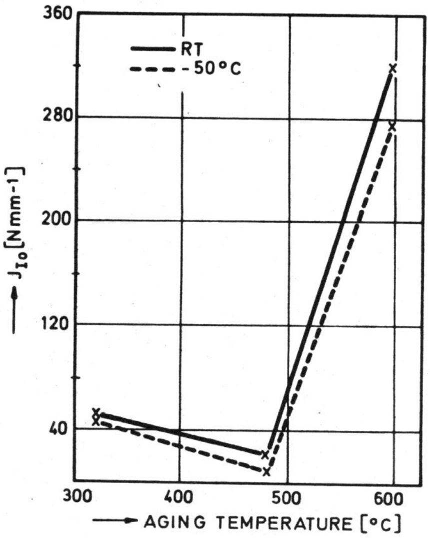

Fig. 4:X3CrNiCuNb155-Influence of Aging Temp. on J_{IO}

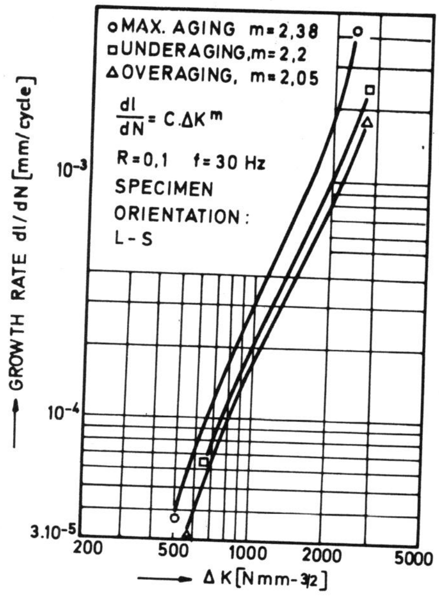

Fig. 5:X3CrNiCuNb155-Influence of Aging Temp.on Crack Propagation

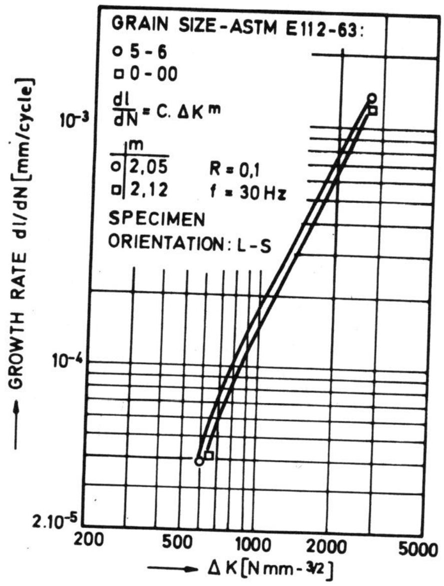

Fig.6:X3CrNiCuNb155-Influence of Grain Size on Crack Propag.

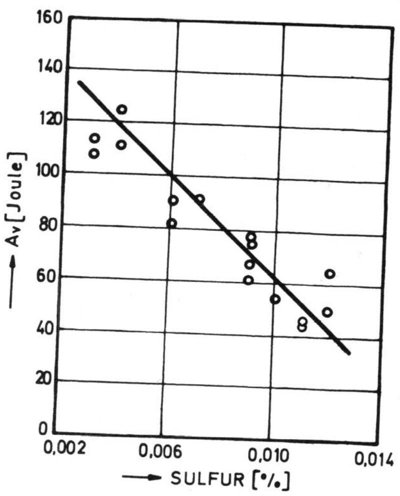

Fig. 7:Influence of Sulfur on impact value

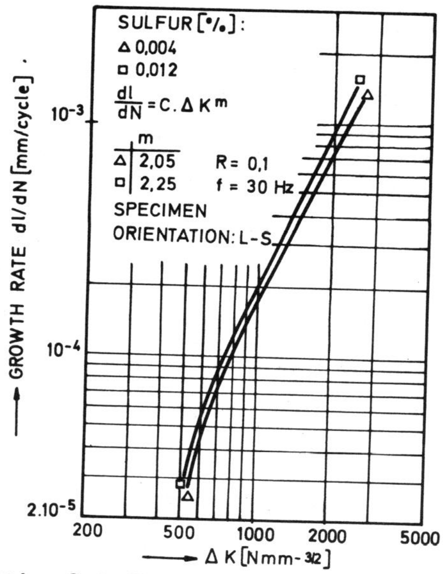

Fig. 8:Influence of Sulfur on Crack Propogation