INFLUENCE OF AGEING ON INTERGRANULAR CRACKING OF 321 HEAT AFFECTED ZONES.

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AISI 321 welded structures may suffer from a serious form of intercrystalline cracking during service at high temperature. This embrittlement, known as stress relief cracking, occurs in the heat affected zone (HAZ) and is related to the fine intragranular Ti(C,N) precipitation. AISI 321 HAZ were simulated by various thermomechanical heat treatments. To analyse the effect of ageing (3000h at 650°C), TEM observations were performed. It was shown that these aged simulated HAZ contained a fine intragranular precipitation of titanium carbides and intergranular sigma phases. It is observed that the creep strain rate is accelerated by ageing. Microgrids were used to show that grain boundary sliding took place preferentially in the aged material. A brief discussion of these observations is made to explain intergranular cracking of 321 HAZ.

INTRODUCTION

Stabilised austenitic stainless steel welded joints are well known to be prone to a serious form of intercrystalline cracking occurring in the material located near the fusion line. This type of damage called reheat or stress relief cracking appears in the heat affected zone (HAZ) during service at high temperature. Many studies have associated this embrittlement with thermal ageing, especially with titanium carbide precipitation which modifies the HAZ behaviour (1-2).

The present work aims to quantify the effects of ageing on the behaviour and on the creep damage of a titanium stabilised heat affected zone. In order to work on homogeneous specimens, HAZ were simulated.

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Stress relaxation tests on « compact tension » specimens have been previously used to reproduce the intergranular damage and to study the cracking sensitivity of the different simulated materials (3). Here, the microstructure of two simulated HAZ was studied by TEM and their creep behaviour was investigated. Moreover, it is discussed how ageing influences HAZ mechanical properties, in particular grain boundary sliding which might promote intergranular cracking in aged material.

EXPERIMENTAL PROCEDURES

Material

The material of this study is an AISI 321 stainless steel. The plate investigated was taken from a real component which had been running at 550°C during 90000h. Its chemical composition is shown in Table 1.

TABLE 1 - Chemical composition of the investigated material (wt %)

C	**Mn**	**Si**	**Cr**	**Ni**	**Mo**
0.059 ±0.002	**1.67** ±0.03	**0.51** ±0.02	**17.9** ±0.1	**10.1** ±0.1	**0.24** ±0.05
S	**P**	**Ti**	**Nb**	**B**	**N**
0.013 ±0.002	**0.027** ±0.002	**0.59** ±0.02	**< 0.05**	**0.0018** ±0.0005	**0.009** ±0.002

To study the mechanical behaviour of 321 welded structures using tests on homogeneous specimens, HAZ were simulated thanks to various thermo-mechanical treatments. The material used in the present study was first submitted to a solution heat treatment at 1200°C during 15 mn. This enabled us to put titanium into solution and to obtain a grain size approaching that observed in real HAZ (150 µm). Then, the materials were cold rolled by 15% and subsequently aged at 650°C during 3000h.

Experimental techniques

The microstructure of the two simulated materials (aged and unaged) was studied by TEM. After mechanical thinning down to 100 µm, thin foils with a 3 mm diameter were prepared by electropolishing in a twin jet device. TEM observations were performed using a Philips EM 430 microscope operating at 300 kV. Microstructural evolution of the HAZ due to ageing at 650°C during 3000h was investigated by usual techniques of electron microdiffraction and bright and dark field imaging.

The simulated HAZ were creep tested at 600°C. Creep tests were essentially carried out in air on conventional smooth bars with an applied stress of 330 MPa which led to rupture times between 100 and 1000h. In order to study the intergranular damage mechanism which is involved in the stress relief cracking of the 321 HAZ, microgrids were used to investigated eventual grain boundary sliding. The surface of these creep specimens tested under vacuum was first mechanically polished and etched to reveal the microstructure. Then, microgrids were deposited following the technique proposed by L. Allais and al (4). But instead of sputtering a thin layer of gold, microgrids were engraved by electrochemical etching of the specimens in a perchloric acid (10%) glycerol (10%) and ethanol (80%) solution. Scanning electron microscope was used to observe the specimen surfaces after creep tests which lasted 200 and 400h.

RESULTS

TEM observations

The cold rolled and aged simulated HAZ microstructure is shown on figure 1, using bright field imaging. A high density of dislocations is observed and no recristallisation is noticed. Numerous particles are observed at grain boundaries. These precipitates were identified as essentially sigma phases. During ageing, a very fine Ti(CN) precipitation (~5 nm) associated with dislocations occurred and can be observed on figure 2. On the other hand in the unaged material, no intragranular secondary titanium carbides and no intergranular precipitates were evidenced. In this material, only some primary titanium carbides were left after the 1200°C-15 mn solution heat treatment.

Creep data

Typical effects of ageing on the creep behaviour of these simulated HAZ are observed on figure 3, where it is shown that the creep rate is drastically increased after an 650°C-3000h ageing treatment. This result is in agreement with those of Adamson and al (5) and those of Cook and al (6) on other stabilised materials. Moreover, ageing seems to have no large effect on creep strain for the onset of both primary and secondary stages since the creep strain at the end of the primary and secondary stages are almost the same for both conditions. The aged material exhibited a larger strain to failure compared to the unaged material (12.9% versus 3.3%).

Sliding study

In order to study the importance of grain boundary sliding in the reheat cracking of 321 HAZ, interrupted creep tests were performed on the two simulated materials. Creep tests were first stopped after 200h. The surfaces of the specimens were observed and the onset of grain boundary sliding was evidenced for the aged HAZ. On the other hand, no evidence of sliding was found on the unaged material. The creep test were then continued up to 400h. Grain boundary sliding was clearly observed in the aged material as shown in figure 4, where the initiation of an intergranular crack at a triple point can be noticed. Once more, no grain boundary sliding and no intergranular damage were observed for the unaged material after 400h creep test. Moreover, the measurements made from the microgrids located within the grains showed that the transgranular strain was very close to the macroscopic creep strain. This stresses the fact that the part of intergranular sliding is negligible in the creep rate, but seems to promote intergranular damage.

DISCUSSION

These results have confirmed that ageing of cold worked 321 stainless steel strongly modifies the microstructure of the material. In this discussion, we would like to concentrate on three aspects : (i) the effect of ageing on the strength (hardness) of the material; (ii) the effect of ageing on the creep strain rate; (iii) ageing in relation with intergranular creep damage.

During ageing at 650°C, there exists a competition between annealing of dislocations produced by cold work and carbide precipitation strengthening. The second mechanism is prevalent when the material is slightly predeformed (~5%), while the first one is most important at large prestrain (~40%) as shown elsewhere (7). This was already partly observed in a previous study (2). In the material prestrained by 15% a balance between both mechanisms was observed since the hardness of the material did not change during ageing up to 3000h. The precipitation strengthening mechanism is usually advanced to explain qualitatively stress relief cracking effect in 321 stainless steel (1). However, the above results show that ageing of a cold worked material may produce contradictory effects depending on the amount of predeformation.

In the present study, it is shown that in 15% cold worked material the ageing produces an increase in the creep strain rate. Similar results have been reported on other stabilised stainless steels by different authors (5-6). This again illustrates the various effects of ageing on the mechanical behaviour of the materials since, as indicated earlier, ageing did not modify the hardness. A decrease of the creep strain rate is expected from the Ti(CN) precipitation. But the reduction of the solute drag effect associated with carbonitride precipitation largely compensates the precipitate strengthening effect. It might be argued that grain boundary sliding which can be observed to occur preferentially in aged material could contribute to this increase of creep strain rate. However, as already indicated, the contribution of grain boundary sliding to overall creep strain is negligible.

The effect of the microstructural modifications, including both transgranular and intergranular precipitation, on the creep damage of austenitic stainless steels has been largely discussed. See in particular Tanaka and al (8) and Kishimoto and al (9) on AISI 321 steel. Our preliminary results seems to indicate that grain boundary sliding is promoted in the aged material. This behaviour which can not be easily explained must be confirmed with further tests. In particular the comparison between the aged and the unaged material must be made at the same overall creep strain. In this comparison, it must be kept in mind that the aged material exhibits a better creep strain to failure compared to the unaged material. However, our observations clearly indicate that grain boundary sliding accelerates intergranular damage by grain boundary cavitations.

CONCLUSIONS

(1) Cold rolled and aged simulated HAZ presented a very fine intragranular titanium carbide precipitation. Moreover, ageing at 650°C significantly modifies the microstructure of grain boundaries where numerous sigma phases are observed.

(2) It is confirmed that ageing may noticeably increase the creep strain rate of these simulated materials. This behaviour is likely related to the reduction of the solute drag effect produced by Ti(CN) precipitation.

(3) Grain boundary sliding seems to play a key role in the reheat cracking mechanism. The creep strain due to sliding is negligible compared to the mean intragranular strain, but grain boundary sliding tends to promote intergranular damage in this aged simulated HAZ material.

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Figure 1 : TEM microstructure of cold rolled and aged material.

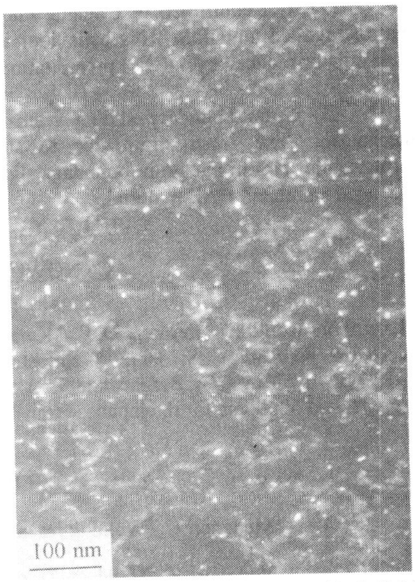

Figure 2 : Fine TiC precipitates (dark field imaging) in cold rolled and aged HAZ.

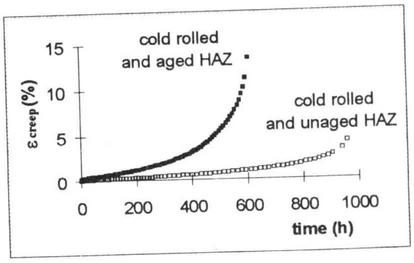

Figure 3 : Creep curves at 600°C under 330 MPa of the material in two conditions.

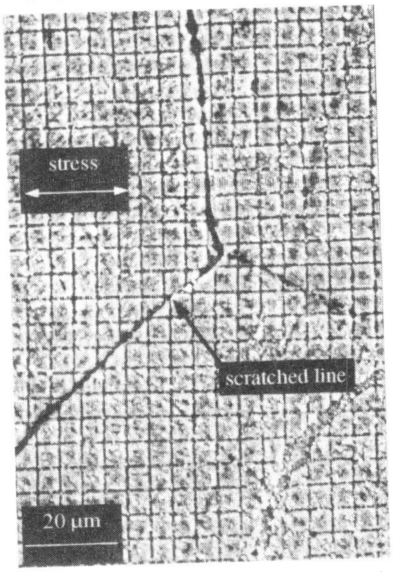

Figure 4 : grain boundary sliding at 400h in cold rolled and aged HAZ.