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Discussion on Influence of σ phase on general and pitting corrosion resistance of SAF 2205 duplex stainless steel by J. H. Potgieter

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Discussion on Influence of σ phase on general and pitting corrosion resistance of SAF 2205 duplex stainless steel by J. H. Potgieter

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There have been a number of publications recently on the effect of σ phase precipitates on the corrosion of duplex stainless steels. That by Potgieter is one such example. All these papers have used single thermal cycles to produce σ phase in their test samples. However, the principal cause of σ phase is welding operations using heat inputs or interpass temperatures which are too high. The study described below shows that there is a significant difference between σ phase produced during welding and that from thermal cycling. There is also a large difference in the corrosion behaviour of material containing σ phase produced in these two different ways. Hence, it is important that corrosion tests in material containing precipitates should be conducted on samples with precipitates having the correct size and distribution.

INTRODUCTION

Zeron 100 (UNS S32760) is a superduplex stainless steel of the nominal composition Fe–25Cr–3·5Mo–7Ni–0·7Cu–0·25N_2–0·7W. Its combination of high strength and good corrosion resistance has led to its widespread use by the oil and gas industry for both sea water and process systems.

Concern has arisen over welds of duplex stainless steels which contain small amounts of σ phase, and the effects this may have on their corrosion resistance.

Precipitation of σ phase occurs when duplex stainless steels are heated in the range 700–1000°C. σ phase can be precipitated during welding operations if the cooling rate from 1200 to 800°C is too slow. This usually occurs because either the heat input is too great or the interpass temperature is too high. σ phase is rich in chromium and molybdenum, which leaves the surrounding matrix depleted in these elements. It is the depleted zones around the precipitates which are then susceptible to corrosion.

EXPERIMENTAL

Materials

Longitudinal sections were cut from 8 in schedule 80s seamless Zeron 100 pipe. These were heat treated at 750°C for short periods to produce a range of σ phase concentrations. Microsections were prepared of the front and back of each sample and electrolytically etched in 10% oxalic acid followed by 40% potassium hydroxide, and the σ phase volume percentage was determined by point counting in accordance with ASTM E562–89 over 30 fields through the full section thickness using a 100 point square grid and a magnification of ×1000.

Welds were produced in two pipes, 2 in schedule 40s and 6 in schedule 10s, by inert gas tungsten arc welding with Zeron 100X overalloyed filler wire. The heat inputs were deliberately increased above optimum values to encourage the precipitation of σ phase. The σ content of each sample was determined as for the thermally cycled material, except that a magnification of ×400 was used.

Corrosion testing

All the samples were immersed in 6% ferric chloride, as per ASTM G48A, at 40°C for 24 h. The weight of each sample was determined before and after testing, and each sample was examined under a low power microscope for pits after testing.

RESULTS AND DISCUSSION

The σ contents and results of the corrosion tests are given in Table 1. It can clearly be seen that although the σ contents of the thermally cycled samples and actual welds were similar, their corrosion behaviour was very different. Both thermally cycled samples showed extensive deep pits on both sides and high weight losses, whereas no pitting was observed on any of the welded samples. Sample 5910/2 showed some weight loss, but this was attributed to some slight general corrosion on part of the weld cap.

The difference between the thermally cycled samples and actual welds is attributed to the nature and distribution of the σ phase. In the thermally cycled material the σ particles were coarse and tended to occur in clumps. The typical diameter of these particles was 14 μm. In the welds the σ occurred in the heat affected zone and was much finer (typically 1·4 μm dia.) and more uniformly dispersed. The greater the volume of the σ particle, the greater the chromium and molybdenum depleted zone around it. The volume increases as the cube of the radius, and hence the σ particles in the thermally cycled material would have a thousandfold greater denuded zone. This would greatly increase the chances of the denuded zones around local clumps of σ phase linking to enable substantial corrosion to occur. The small denuded areas around the σ phase in the welded samples, and the fact that the σ phase was

Table 1 Results of ASTM G48 Method A tests for thermally cycled and welded Zeron 100

Treatment	Specimen	σ conc., vol.-%	Visual examination	Weight loss, mg
Thermally cycled	90	1·0*	Extensive pitting	170
	95	1·6*	Extensive pitting	44
Welded	5910/1	1·5	No pits	4
	5910/2	1·5	No pits	22†
	5572/6	1·4	No pits	4
	5572/12	1·5	No pits	0

*Mean of front and back values.
†*See* text.

more uniformly distributed, would make linking of the denuded areas, and hence substantial corrosion, less likely. This theory explains why pitting occurred only on the thermally cycled samples.

It is clear from the present work that thermal cycling does not produce σ phase in the same way that can occur during welding. This is probably because welding of thin wall pipe usually requires two, three, or even four passes. Thus, not only are the heated areas very local, but areas are heated several times, between different temperatures, and cool at different rates during the welding operation. Hence a single thermal cycle cannot be judged to reproduce properly the microstructures that can occur during welding.

CONCLUSIONS

1. Small quantities (~1·5 vol.-%) of σ phase produced during welding of Zeron 100 superduplex stainless steel do not significantly decrease the corrosion resistance as assessed by the ASTM G48 Method A ferric chloride test.
2. A single thermal cycle at 750°C produces a coarser, less uniform distribution of σ phase than welding, which renders the material less resistant to pitting in the ferric chloride test.

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The author replies

I should like to thank Dr Francis for his valuable comments and contribution regarding the effect of σ phase on the corrosion behaviour of duplex stainless steels. The size and distribution of the σ phase particles is no doubt a major factor influencing the corrosion behaviour of these steels, over and above the volume fraction thereof. However, this observation on his part does not influence my conclusion regarding the general corrosion resistance in sulphuric acid solutions.

As far as the pitting corrosion resistance of duplex stainless steels containing σ phase is concerned, it should be kept in mind that the σ phase contents of $\geqslant 6$ vol.-% in my investigation were much higher than one would normally come across in practical situations, so my observation concerning the influence of σ phase on pitting resistance is also still valid. I concede that the single thermal cycle used to precipitate σ phase is not an adequate simulation of welding practice.

My investigation's conclusions are concerned with a type of 'worst case' situation; real life practical experience is generally far less serious. In this regard Dr Francis's observation that finely dispersed σ phase particles present at contents of as much as 1·5 vol.-% cause no pitting corrosion problems in duplex stainless steel welds indicates once again how well suited this material is for use in chloride containing media.

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