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EFFECT OF QUENCHING TEMPERATURE ON MICROSTRUCTURE AND PROPERTIES OF CAST DUPLEX STAINLESS STEEL

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ABSTRACT

This paper considers the influence of microstructural changes obtained by suitable heat treatment on impact toughness and pitting corrosion resistance of cast duplex stainless steel 0.08C-22.5Cr-8Ni-2Mo-3.5Cu. Investigated steel was annealed in the temperature range from 1000 to 1300 °C for 1 h and water quenched. Microstructure of specimens obtained from broken Charpy bars was characterized quantitatively using a semi-automatic image analyser. The stereological parameters: V_V, S_V and S_V / V_V were estimated by a linear method. The localized corrosion behavior was studied in 0.5 M NaCl using the potentiodynamic anodic polarisation method. The changes in microstructure are pronounced from 1100 °C. In comparison with the cast structure ferrite/austenite ratio gradually increases while the surface density and specific surface decrease. The impact toughness, however, reaches a maximum at 1100 °C and then decreases. The corrosion resistance of all heat treated alloys is improved. The lowest current density and best resistance to pit initiation are achieved by annealing in the range from 1100 to 1210 °C. The results indicate that the ferrite/austenite ratio itself is a very important but not a single factor determining the mechanical and corrosion properties of cast duplex steel.

Keywords: cast duplex stainless steel, corrosion resistance, impact toughness, microstructural changes, stereology.

INTRODUCTION

Cast duplex stainless steels composed of ferrite and austenite phases, have found extensive applications in the chemical, petrochemical and oil industries where the high strength, toughness and good corrosion resistance, particularly to chloride ion induced localized corrosion are required (Atamert and King, 1991; Tawancy and Abbas, 1988). Unique combination of the mechanical properties and corrosion behavior of the such duplex steels is obtained by suitable chemical composition and microstructure. The increasing of chromium, molybdenum and nitrogen contents as well as copper additions increase corrosion resistance and induce precipitation hardening (Sriram and Tromans, 1989; Pohl et al., 1991). Recently, it was found that the addition of copper leads also to the refinement of the microstructure (Soylu and Honeycombe, 1991). The microstructure is shown to have a significant influence on both mechanical properties and corrosion resistance.

The microstructural parameters, which may affect the properties are the ferrite/austenite ratio, partitioning of alloying elements and phases morphology. The superior properties beside uniformly distributed alloying elements can be achieved by appropriate ferrite/austenite proportion,amount and distribution of ferrite/austenite boundary area. Although the influence of microstructural features on the properties of cast duplex stainless steels is well known, only few investigations on the structure-property relationships have been done. Several studies which can be found in the literature relate on the partitioning of the elements (Sriram and Tromans,1989) or wrought duplex stainless steels (Rosenheinrich and Zum Gahr,1989).

Therefore, the purpose of the present investigation was to assess the effect of heat treatment on the microstructure of cast duplex stainless steel and to determine the major microstructural features controlling the impact toughness and pitting corrosion resistance.

EXPERIMENTAL PROCEDURE

Commercial cast stainless steel of the composition (in wt-%): 0.08C-22.5Cr-8Ni-2Mo-3.5Cu was used in this investigation. Test samples were taken from central region of the as-received rectangular block with dimensions 30x70x300 mm produced by the sand casting process.

A standard V-notched Charpy specimens were machined from material in as-cast condition and heat treated to obtain different microstructural features. Charpy specimens were annealed at 1010, 1100, 1165, 1210, 1250, 1280 and 1300 °C for 1 h and subsequently water quenched. Room temperature impact tests were carried out. Transverse sections of the broken specimens were prepared by standard metallographic techniques for optical microscopy. The microstructure was revealed by etching in a solution of 2g picric acid, 10 cm^3 HCl and 100 cm^3 ethanol at 25 °C. The microstructural changes were characterized quantitatively using a semi-automatic image analyser. The following stereological parameters: volume fraction of ferrite, V_{VF}, and austenite, V_{VA}, density of ferrite/austenite interface, S_{VF-A}, and specific surface of austenite boundary, S_{VF-A} / V_{VA}, were estimated by a linear method.

The localized corrosion behavior was studied using potentiodynamic and potentiostatic techniques. The potentiodynamic anodic polarisation of the polished specimens was carried out in 0.5 M NaCl. The electrode potential was measured with respect to a saturated calomel electrode (SCE). The anodic polarisation was started at open circuit potential (E_{ocp}) and scanned at a rate of 0.2 mV/s. The potential at which the anodic current density increased rapidly was taken to be the pitting potential (E_p). Pitting resistance, according to a proposal made by McIntyre et al.(1991), was determined by the difference between E_p and E_{ocp} (ΔE). In order to locate more accurately the position of the pitting potential the potentiostatic polarisation test was performed on the specimens in as-cast condition and after annealing at 1100 °C. The potential was applied for 5 hours and the change in current with time was recorded. The location of pitting sites was examined after potentiostatic test using optical microscopy (OM).

RESULTS AND DISCUSSION

A. Microstructure

Typical microstructure of examined steel in as-cast and after subjected to different heat treated conditions are illustrated in Fig.1. All the micrographs show austenite in a matrix of ferrite, some amounts of non-metallic inclusions and nitride. The second phase particles at ferrite/austenite phase boundary are also sporadically observed in the initial as-cast structure and after annealing at 1010 °C. Since particular attention was paid to morphological changes of predominant aus-

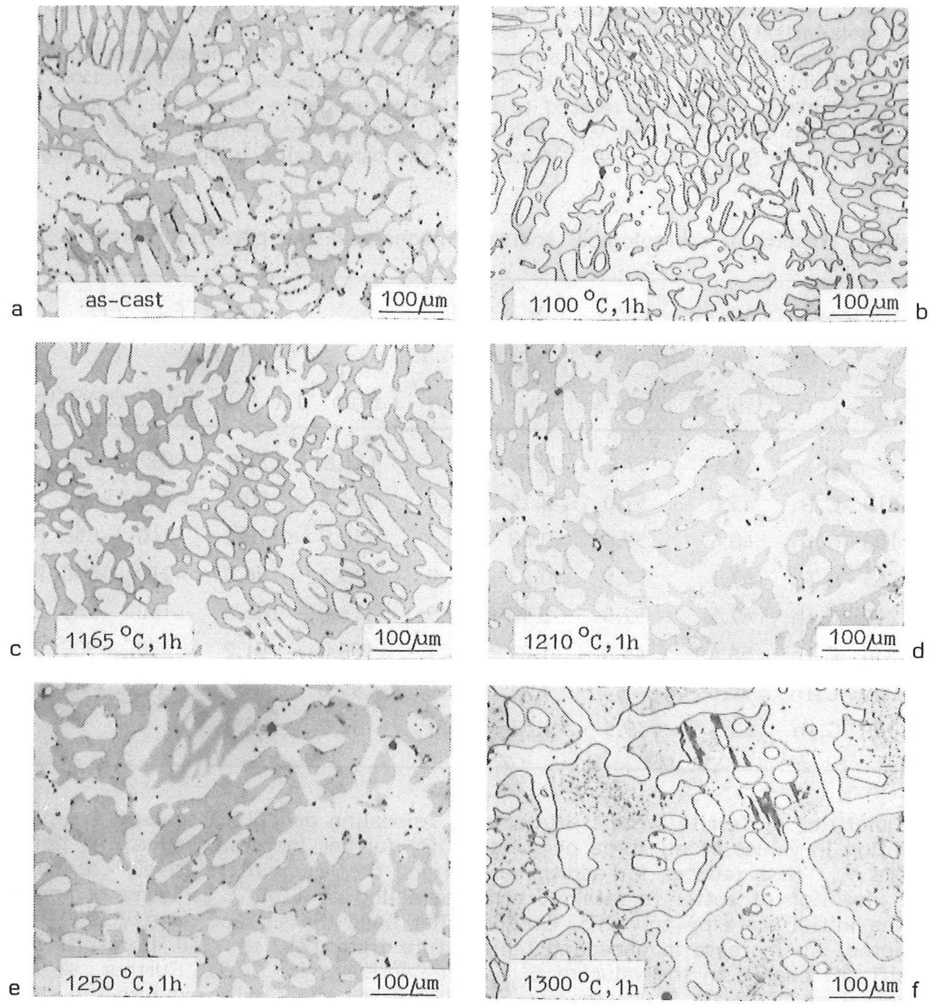


Fig.1. Optical micrographs showing effect of annealing temperature on the microstructure of duplex stainless steel 0.08C-22.5Cr-8Ni-2Mo-3.5Cu. The specimens were water quenched after annealing. Type of phases: austenite (bright contrast), ferrite (dark contrast), non-metallic inclusions and nitride (black spots).

tenite and ferrite phases, a detailed examination of other particles was not performed.

The microstructural analysis revealed that ferrite/austenite ratio and austenite morphology change with increasing annealing temperature. However,the microstructural features are not affected much when the material is annealed at 1010 °C or even at 1100 °C, as shown in Fig. 1b. The effect is more pronounced for temperatures above 1100 °C. The volume fraction of austenite decreases due to transformation into ferrite, while its morphology changes from relatively discontinuous network to continuous layer along the grain boundaries; also,the boundary initially rugged takes up less irregular and almost smooth appearance (see Figs. 1c-f).

Austenite particles present within the ferrite grains tend to become globular. Complete globularisation is noticed after annealing at 1300 °C, Fig. 1f.

The results of stereological analysis are consistent with the observed changes in microstructure. As it can be seen from Table 1 the phases volume fraction and both parameters, which are related to the ferrite/austenite interface remain unchanged up to 1165 °C. Then V_{VA} and S_{VF-A} decrease by about 11% and 13% respectively, while S_{VF-A} / V_{VA} has almost the same value indicating unchanged

Table 1. Results of stereological analysis, mechanical and potentiodynamic tests.

Condition	V_{VF} (vol.%)	V_{VA} (vol.%)	V_{VF}/V_{VA}	S_{VF-A} (mm^{-1})	S_{VF-A}/V_{VA} (mm^{-1})	Impact energy (J)	E_{ocp} (mV)	E_p (mV)	ΔE (mV)
as-cast	42.4	57.6	0.74	64.4	111.8	77.5	-185	+300	485
1010 °C,1h	43.0	57.0	0.75	65.4	114.7	80.0	-230	+600	830
1100 °C,1h	40.4	59.6	0.68	70.3	117.9	110.0	-240	+850	1090
1165 °C,1h	47.1	52.9	0.89	61.0	115.3	104.0	-210	+850	1060
1210 °C,1h	47.5	52.5	0.90	59.9	114.0	105.0	-150	+980	1130
1250 °C,1h	56.4	43.6	1.29	47.1	108.0	91.2	-70	+900	970
1280 °C,1h	58.6	41.4	1.41	41.0	99.0	-	-135	+900	1035
1300 °C,1h	60.5	39.5	1.53	34.6	87.6	100.0	-	-	-

irregularities of ferrite/austenite interface. Annealing at 1210 °C causes a similar variation in values of all three parameters. By further increasing annealing temperature V_{VA} first reduces for additional 17% and then remains relatively constant. The fraction of austenite retained after annealing at 1300 °C is lower compared to the initial state by only 32%. On the other hand the surface density is stronger affected. An increase in annealing temperature from 1210 to 1250 °C results in a significant change in the value of S_{VF-A} ; it decreases for 21.5%. Further, as the temperature increases S_{VF-A} progressively decreases and finally exhibits the value lower for 46% in comparison to the cast material. Specific surface shows a similar variation with increasing annealing temperature, but it decreases a much slower.

B. Mechanical and corrosion properties

The values of notch impact energy and data of potentiodynamic test together with estimated stereological parameters are summarized in Table 1. It can be noted that impact toughness reaches a maximum at 1100 °C and then gradually decreases up to 1300 °C when again slightly increases. Disagreement of such a variation in impact energy with observed trend in austenite volume fraction indicates that ferrite/austenite ratio is influential (Pohl et al.,1991) but not a single factor controlling impact toughness. The fact that material annealed at 1100 °C exhibits superior toughness, although a variation in ferrite/austenite ratio is not pronounced leads to the conclusion that improved toughness can be associated with dissolution of second phase particles. The gradual decrease in impact energy with increasing annealing temperature from 1100 to 1250 °C may be the result of two effects, (1) decreasing austenite fraction, and (2) decreasing amount of ferrite/austenite boundary area. The increase of toughness at 1300 °C, however, can be explained only with described change in austenite continuity.

The electrochemical behavior of examined steel in 0.5 M NaCl shows a similar dependence on microstructural changes. The potentiodynamic anodic polarisation curves for various heat treated samples are shown in Figs. 2a and 2b. The as-cast polarisation curve is presented as the reference curve in each figure. From these figures and Table 1 it can be seen that the employed heat treatments ensure improved corrosion resistance. All curves obtained for annealed samples are characterized by lower current density and nobler pitting potentials. However, looking

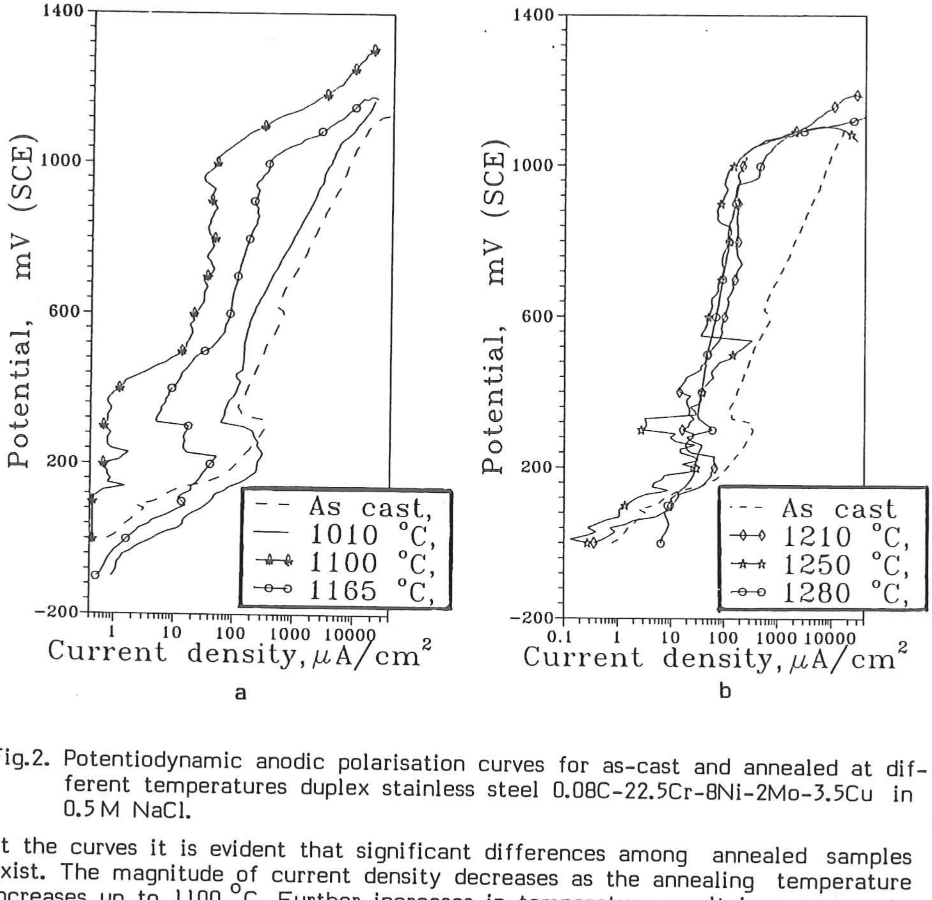


Fig.2. Potentiodynamic anodic polarisation curves for as-cast and annealed at different temperatures duplex stainless steel 0.08C-22.5Cr-8Ni-2Mo-3.5Cu in 0.5 M NaCl.

at the curves it is evident that significant differences among annealed samples exist. The magnitude of current density decreases as the annealing temperature increases up to 1100 °C. Further increases in temperature result in a reversed tendency. In the temperature range from 1210 to 1280 °C the curves are displaced to higher current densities but not over those of the cast material. Also, the pitting potentials continually raises to 1210 °C, when is identified as +980 mV(SCE), and subsequently decreases to +900 mV(SCE). The results clearly show that E_p of annealed samples are much nobler than the corresponding potential for the cast material, which is equal to +300 mV(SCE), but the absolute value of E_p is not the best measure of the pitting resistance. Pitting resistance is better determined by the ΔE value. As the greater difference between E_{ocp} and E_p values the material will be more resistant to pit initiation. Thus, the best resistance to pit initiation is achieved by annealing in the range from 1100 to 1210 ^{o}C due to the fact that the E_{ocp} value increases to the more active side up to 1100 ^{o}C and than becomes nobler than those of the cast material. This trend in corrosion behavior like in the case of impact toughness is caused by different effects. The samples annealed at 1010 and 1100 ^{o}C show no change in stereological parameters. Consequently, the good corrosion resistance can be attributed to the dissolution of second phase particles and a decrease in segregation level. At the temperatures above 1100 ^{o}C extensive microstructural changes occur. In this temperature range ferrite/austenite ratio increases, while S_{VF-A} and S_{VF-A}/V_{VA} decrease. The changes are more pronounced above 1210 ^{o}C,when the somewhat easier occurrence of pitting is observed. It could then be concluded that above the temperature of second phase dissolution corrosion behavior should be associated primarily with the ferrite fraction, amount and irregularity of ferrite/austenite interface. This is consistent with OM observations on potentiostatic tested material. Figure 3 clearly

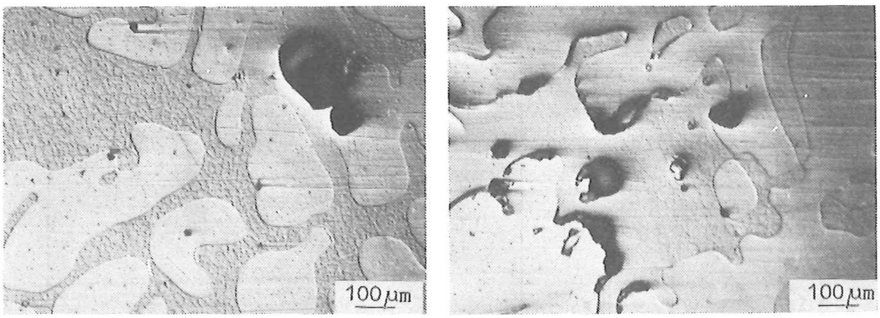
a  b

Fig.3. Duplex stainless steel 0.08C-22.5Cr-8Ni-2Mo-3.5Cu annealed at 1100 ^{o}C showing dissolution of ferrite and pitting attack at inclusions and ferrite/ austenite interface after potentiostatic test.Nomarski interference contrast.

shows preferential dissolution of the ferrite. Also, it can be seen that although the inclusions may act as pitting sites, additional pitting attack occurs at ferrite/ austenite interface.

From these results, it appears that complex effects of microstructure prevent prediction of impact toughness and corrosion susceptibillity solely on the basis of ferrite/austenite ratios. The amount,distribution and morphology of ferrite/austenite interface as well as partitioning of alloying elements must also be taken into consideration.

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