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Ductile to Brittle Transition Behavior of Super Duplex Stainless Steels

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Abstract: Duplex stainless steels (DSS) are a group of steels consisting of approximately equal volume fraction of austenite and ferrite. In this study, the influences of the factors such as hydrogen, ferrite phase, cold deformation, grain size, and cluster due to the spinodal decomposition and precipitates or secondary phases in a super duplex stainless steel on the ductile to brittle transition (DBT) are investigated. Three types of DBT curves: toughness versus temperature, hardness and amount of precipitates, have been built to describe the DBT behavior in DSS. These curves are important to provide the information about the critical conditions or criteria where a possible ductile to brittle transition can occur. They can be used as references for different applications.

Keyword: Toughness, Duplex stainless steels, Ductile to brittle transition, Cleavage, DBTT

1 Introduction

As known, toughness is the ability of a metal to absorb energy and deform plastically before fracture. It depends strongly on type of material and conditions. The metals with body-centered cubic structure such as ferritic steels can have a ductile to brittle transition with decreasing temperature. This is often associated with a change in fracture mode of ductile dimples to cleavage. Susceptibility to cleavage fracture can be enhanced by increase of strength such as at low temperature and formation of stress raiser such as micro crack or precipitates [Anderson (1995)].

Duplex stainless steels (DSS) are a group of steels that have a combination of good corrosion resistance and high strength and toughness, and widely used in oil and chemical industries [Nilsson (1992), Charles (1991)]. However, their application temperatures are usually limited. The modern duplex stainless steels consist of approximately equal volume fraction of austenite and ferrite, and therefore a ductile to brittle transition at low temperatures is a concern. On the other hand, different precipitates or undesirable secondary phases may form during isothermal ageing or incorrect heat treatment at temperatures higher than 300°C [Nilsson (1992)], which can cause a significant decrease in toughness of the material. There are a plenty of studies on the factors affecting toughness of the duplex stainless steels [Nilsson (1992), Charles (1991)]. However, less investigation has been done on the factors that affect the ductile to brittle transition behavior. In this paper, the influences of the factors such as ferrite content, cold deformation, phase size and different precipitates on the ductile to brittle transition behavior of a super duplex stainless steel are discussed.

2 Material and experimental procedures

The material used is super duplex stainless steel (SDSS): UNS S32750 with a nominal chemical composition of 7Ni4Mo25Cr1,2Mn0,3N0,8Si0,03C73Fe in wt%. The samples were taken from a tube with an outer diameter of 260mm and a wall thickness of 14mm. Two types of toughness tests (impact toughness and CTOD) have been performed in a temperature range from -196°C to 600°C. Two to three samples/temperature were tested and an average value was used in the impact toughness versus temperature or DBT curves. In this paper, the following two methods have been used to determine a ductile to brittle transition temperature (DBTT). The first is to determine the temperature, T50, from a ductile to brittle transition curve modeled by the following equation with 50% probability [ASME VIII, (1989), EN

Table 1: Influences of the different factors on DBTT

DBTT	Reference	Ferrite content (%)			Cold deformation (%)				Austenite spacing (μm)		
(°C)		45	61	68	0	5	10	15	18	23	32
T50	-86	-74	-58	-41					-74	-76	-72
T90J	-100	-92	-74	-54	-85	-76	-58	-52	-92	-94	-90

13445, (2002)].

$$KV = \frac{(KV_{\max} - KV_{\min}) \times \exp\left(\frac{2\times(T-T_{50})}{C}\right)}{1+\exp\left(\frac{2\times(T-T_{50})}{C}\right)} + KV_{\min}$$

Another method is fracture analysis. DBTT is the temperature where no cleavage could be observed on the fracture of an impact sample under a scanning electron microscopy (SEM). In this investigation, no cleavage could be observed on the fracture of the sample with impact toughness higher than 90joules. Therefore, T90J is another definition of DBTT for this material.

3 Results and discussion

3.1 *Influence of temperature on DBT behavior*

Figure 1 shows the DBT curves from the CTOD and the impact toughness tests. It is expected that both CTOD and impact toughness decrease with decreasing temperature. The curves modeled using equation 1, where C=35 is used, are used to determine T50 and T90J. Table 1 is a summary of the influences of the factors such as amount of ferrite, cold deformation and phase size on the DBTT. It shows that the influence of phase size on the DBTT is relatively small. This result is quite different from that of the weld material where the DBTT (T27J) increases significantly with increasing grain size [Lindblom, et al. (1991)]. As expected, an increase in ferrite content will raise the DBTT, but the upper levels of impact toughness are comparable at high temperature. This is due to the fact that it is the ferrite that causes a DBT. The cold deformation decreases the upper level of impact toughness and also increases the DBTT. Cold deformation increases both the strength of the material and the density of dislocation, which will promote the tendency for cleavage [Anderson (1995)].

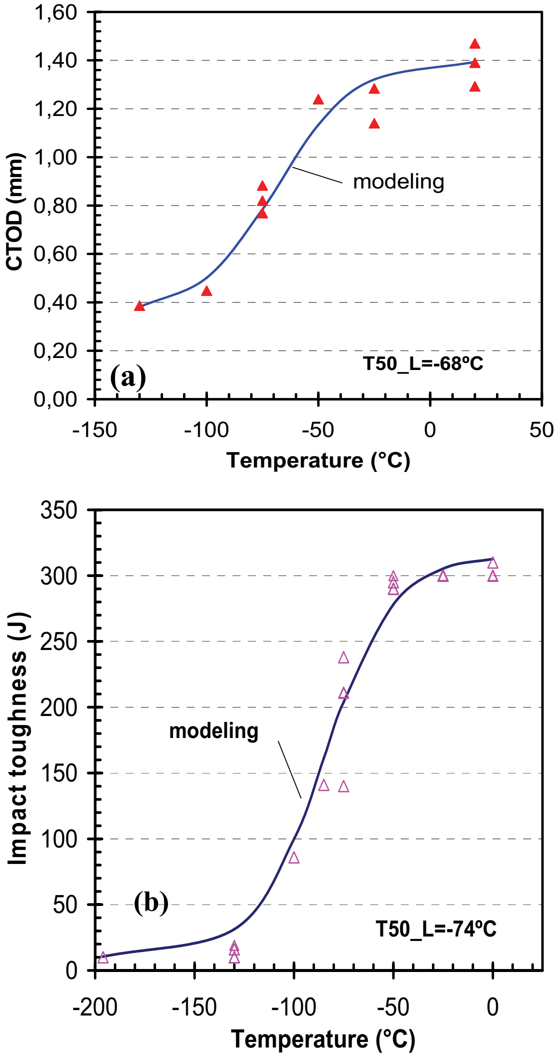

Figure 1: DBT behavior of UNS S32750 SDSS, (a). CTOD (b). Impact toughness.

3.2 *Influence of cluster on DBT behavior*

SDSS can suffer from a spinodal decomposition at temperatures between 300-500°C where the ferritic phase separation gives concentration vari-

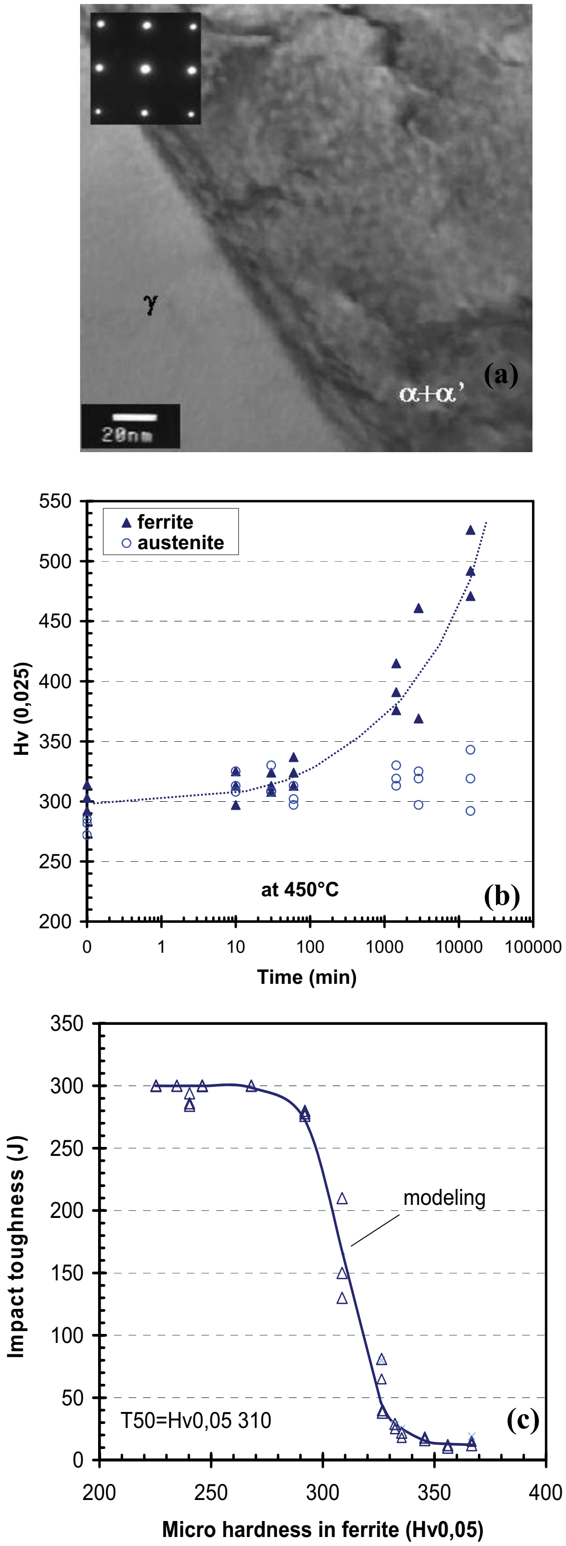

Figure 2: Influence of spinodal decomposition on DBT of DSS, (a). Formation of cluster (b). Influence of spinodal decomposition on the hardness of individual phases, (c). Impact toughness.

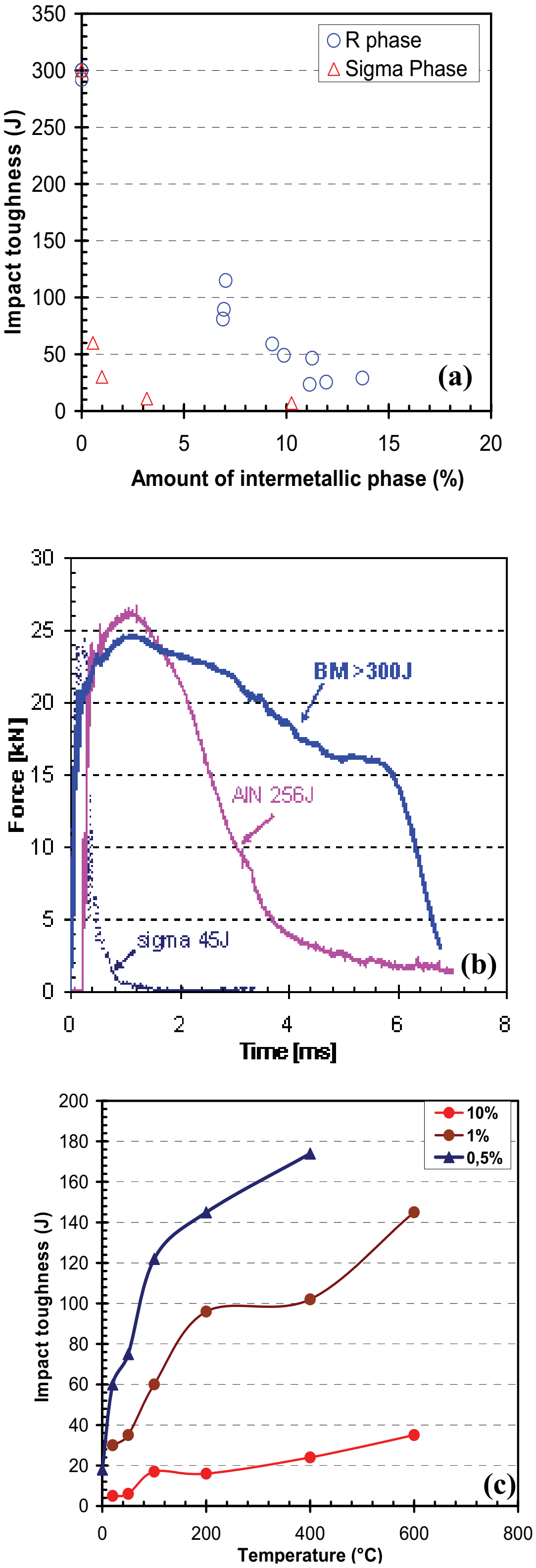

Figure 3: Influence of precipitates on the DBT behavior of SAF 2507.

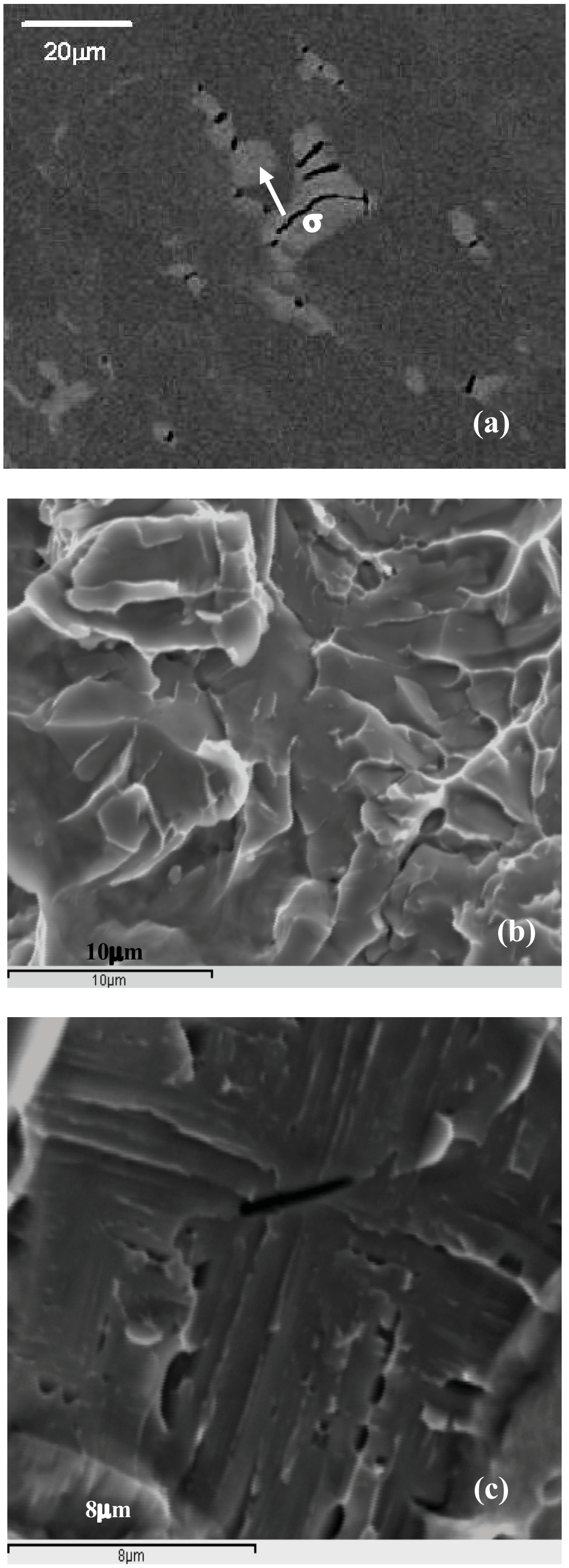

Figure 4: Influence of precipitates on cleavage in SDSS. (a). Cracking of sigma phase, (b). Cleavage fracture in the material with sigma phase, (c). Cleavage initiation at an AlN particle.

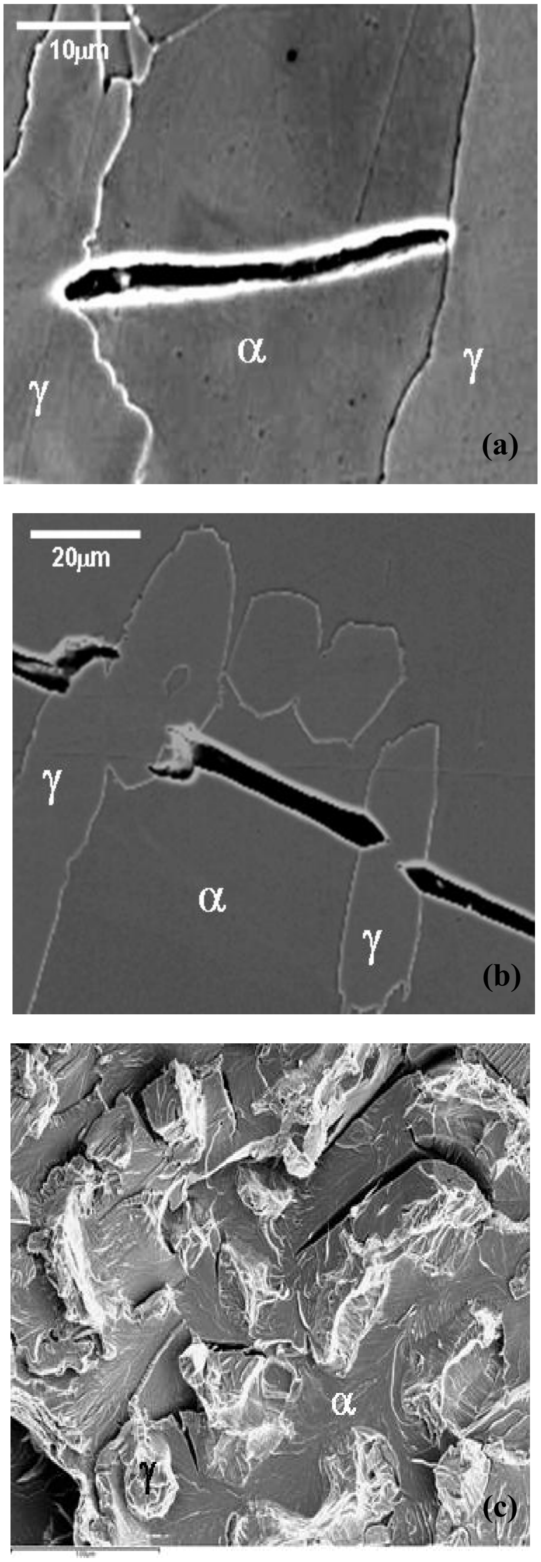

Figure 5: Cleavage initiation and propagation in hydrogen enriched SDSS, γ-austenite, α-ferrite.

ations with Fe-rich (α) and Cr-rich (α') regions (Figure 2a) and Fe-rich and Cr-rich clusters will form [Nilsson (1992), Charles (1991)]. Spinodal decomposition leads to an increase in the hardness of the ferritic phase, but not the austenitic phase (Figure 2b). It was found that an increase in hardness of the ferritic phase promotes the occurrence of cleavage or DBT (Figure 2c). Using equation 1, the hardness at T50 and T90J can also be determined as shown in Figure 3c. This type of curve provides useful information for a quick evaluation of the influence of spinodal decomposition on the brittleness of the material.

3.3 Influence of precipitates on DBT behavior

It is reported that formation of precipitates or secondary phases can significantly reduce the impact toughness. The material with sigma phase higher than 1% can start to become brittle [1, 3]. In this investigation, it was found that the influences of different precipitates on the DBT behavior are different (Figure 3a and b). The formation of sigma phase causes a rapid decrease in impact toughness with increasing amount of sigma phase. However, the formation of other precipitates such as R and AlN phases does not show similar detrimental effect as that of sigma phase (Figure 3a and b). The force versus time curves from an impact toughness test show that the formation of cleavage in the SDSS with sigma phase need much less crack initiation energy and crack propagation energy comparing with the material with AlN phase (Figure 3b).

The different DBT behavior from different precipitates depends on the nature of precipitates and fracture mechanisms. Sigma phase has a $P4_2/mnm$ structure and is brittle. They precipitate mainly along grain or phase boundaries. These particles become easily cracking during plastic deformation, which occurs usually through the particle as shown in Fig 4a. These sharp microcracks then become the stress raisers that provide a local stress and strain concentration for the occurrence of cleavage in the ferritic phase (Figure 4b). The presence of sigma phase even affects the DBT behavior at high temperatures. High amount of sigma phase will not cause a brittle to ductile transition even at temperature higher than 600°C (Figure 3c). The other precipitates such as R and AlN phases are small and precipitate mainly in the grains. These particles have coherent bonds with the matrix. This indicates that they behave as a local discontinuity. The stress concentration forms mainly by the accumulation of plastic deformation or dislocations, which causes a cleavage initiation (Figure 4c).

Hydrogen in SDD can also cause a DBT. Different from one single phase material, the austentic phase in SDSS can become a stopper for cleavage initiation (Fig 5. a) and propagation (Figure 5b). Cleavage fracture propagates discontinuously. This creates an unusual top-valley fracture (Figure 5c).

4 Concluding remarks

Three types of DBT curves: toughness versus temperature, hardness and amount of precipitates, have been built to describe the DBT behavior in DSS. Influences of small variations of the microstructure such as phase size, ferrite content and cold deformation on the DBTT are small. Spinodal decomposition and precipitates can significantly raise the DBTT. The cleavage propagation in DSS can be discontinuous since the austenitic phase behaves as a stopper.

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