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Viewpoint Paper

Liquid zinc embrittlement of twinning-induced plasticity steel

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Abstract—The susceptibility of a Fe22Mn0.6C twinning-induced plasticity steel to liquid zinc embrittlement has been investigated by performing hot tensile tests on bare and electrogalvanized specimens using a Gleeble thermomechanical simulator. Tensile tests were carried out at different temperatures and strain rates. The studied steel can be severely embrittled by liquid zinc (drastic reductions in elongation at rupture and fracture strength) given particular conditions of temperature and strain rate.

Keywords: TWIP steel; Austenitic steel; LME; Tension test; Coating

1. Introduction

High manganese austenitic steels are particularly promising material for automotive applications because of their combination of high work-hardening rate, high tensile strength and large ductility. Such exceptional properties stem from a fully austenitic structure at room temperature and a competition between the classical mechanism of dislocation glide and the twinning deformation mode, known as the twinning-induced plasticity (TWIP) effect [1–5]. The different structural pieces of an automotive body are joined by welding. Three welding processes are mainly used in the automotive industry: resistance spot welding, arc welding and laser welding. During such processes, because of the high temperatures reached at the sheet's surface, the zinc coating applied for corrosion protection is likely to melt due to its low melting point of 420 °C. The presence of liquid zinc combined with the presence of high stresses generated by the thermomechanical welding cycle can lead to the liquid metal embrittlement (LME) phenomenon. This results in a catastrophic deterioration of the material's mechanical properties [6]. The mechanisms involved in this phenomenon are not yet fully understood, so its occurrence cannot be accurately predicted [7,8]. However, some solid metal/liquid metal couples are known to be prone to the LME phenomenon. Among them are Al_{solid} with Ga_{liquid} [9,10], Cu_{solid} with Bi_{liquid} [11], martensitic steels with Pb_{liquid} [12,13] or Pb-17Li_{liquid} [14] and austenitic stainless steels with Zn_{liquid} [15,16]. However, to the authors' knowledge, no investigation dealing with the embrittlement of austenitic TWIP steels by liquid zinc has been reported in the literature.

In order to use the full potential of TWIP steels in automotive applications, the welding behaviour of such steels must be validated. Cracking resulting from liquid zinc embrittlement during spot welding of dual-phase steel and transformation-induced plasticity steel has been reported by Sigler et al. [17]. They noted that microstructures that are fully transformed to austenite during thermal cycle appear much more sensitive to cracking. Thus, investigations to determine the behaviour of austenitic TWIP steels in the presence of liquid zinc and to understand the embrittlement mechanisms of liquid zinc are needed in order to adapt welding procedures to avoid cracking during processing.

In this work, the behaviour of an austenitic TWIP steel in the presence of liquid zinc was studied using simple uniaxial tensile loading of electrogalvanized specimens at high temperature. The hot tensile test used in this study is particularly appropriate for investigating the embrittlement of Fe–22 wt.% Mn–0.6 wt.% C TWIP steel by liquid zinc and examining the influence of different parameters on the severity of embrittlement.

2. Experimental

The chemical composition of the investigated TWIP steel is Fe–22.6 wt.% Mn–0.58 wt.% C. Specimens were supplied by ArcelorMittal Research SA Maizières. This

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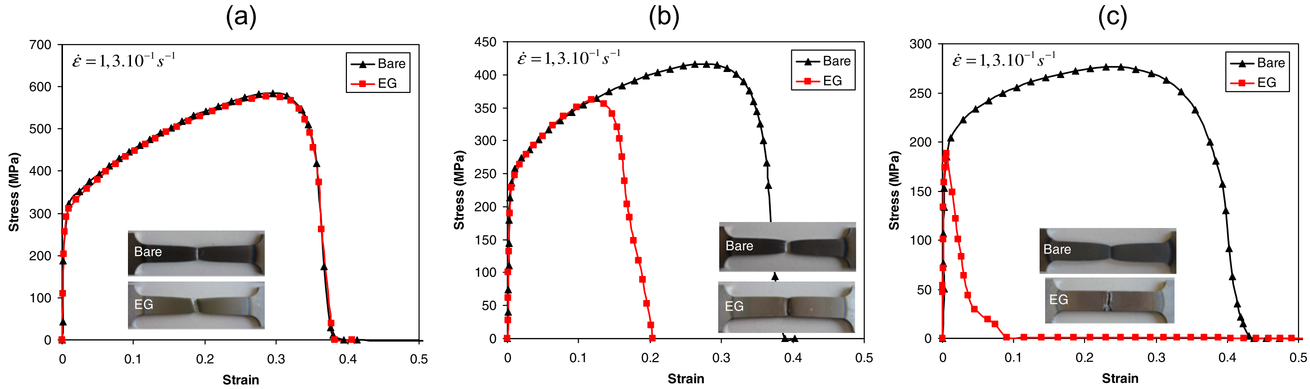

Figure 1. Tensile curves of bare and electrogalvanized (EG) specimens obtained at different temperatures: (a) 600 °C, (b) 700 °C and (c) 800 °C.

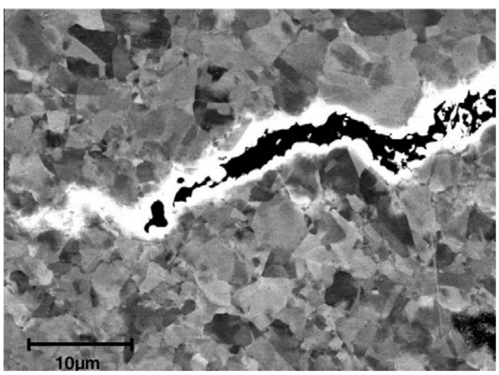

Figure 2. Scanning electron microscopy micrograph of the transverse section of a cracked specimen.

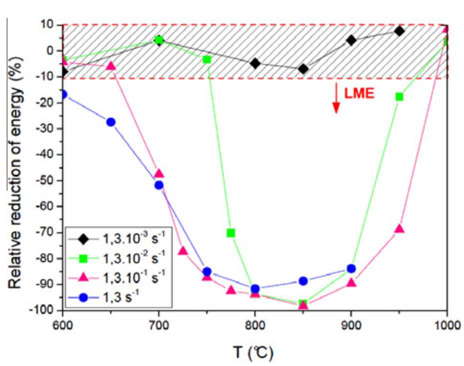

Figure 3. Ductility trough of the Fe22Mn0.6C steel in the presence of liquid zinc for different strain rates.

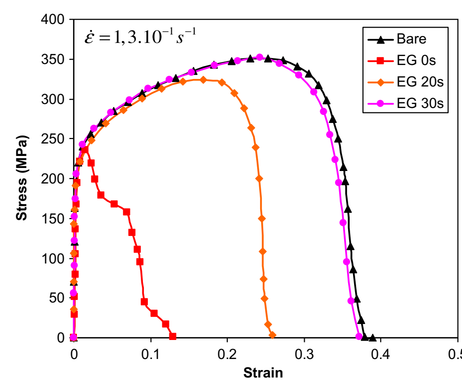

Figure 4. Tensile curves obtained at 750 °C (strain rate 0.13 s^{-1}): progressive ductility recovery after holding at 750 °C.

steel is fully austenitic at room temperature and exhibits no phase transformation in the studied temperature range (420 °C $\leqslant T \leqslant$ 1000 °C) [4].

The behaviour of the TWIP steel in the presence of liquid zinc has been investigated by hot tensile tests, the contact with liquid zinc arising from the melting of the zinc coating. Hot tensile tests were also performed with bare specimens to determine the reference behaviour of the steel. Tensile tests were carried out at different temperatures (600 °C $\leqslant T \leqslant$ 1000 °C) and at four different strain rates: 1.3×10^{-3}, 1.3×10^{-2}, 1.3×10^{-1} and 1.3 s^{-1}. A Gleeble thermomechanical simulator was used to conduct tension experiments. The main advantages of such equipment are the high heating rate available due to heating by the Joule effect, the wide ranges of temperature and strain rate and the possibility of using an extensometer to measure the deformation. A detailed description of the experimental procedure can be found in Ref. [18].

3. Results and discussion

Tensile curves obtained with bare and zinc-coated specimens at different temperatures with a strain rate of 1.3×10^{-1} s^{-1} are shown in Figure 1. At 600 °C (Fig. 1(a)), the tensile tests performed on the bare and electrogalvanized specimens give the same results. Thus, it can be concluded that liquid zinc has no detrimental effect at 600 °C. At 700 °C (Fig. 1(b)), the electrogalvanized specimen exhibits reduced ultimate tensile strength and elongation at fracture compared to the bare one. In this case, embrittlement results in a partial loss of ductility. It is worth noting that the presence of liquid zinc does not affect the mechanical behaviour of the steel until the premature fracture. The steel is more severely embrittled at 800 °C (Fig. 1(c)), with the ultimate tensile strength and elongation at fracture being drastically reduced in the presence of liquid zinc. In this case, cracking occurs at a very small strain and thus the coated specimen exhibits very little macroscopic deformation