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A Novel Method of Reducing Residual Stress: Low Transformation Temperature (LTT) Weld Filler

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Abstract

An innovative, alternative method to improve the undesired residual stress state during the welding process without time-consuming post weld treatments was overviewed. The LTT 'smart' alloy weld filler can effectively reduce the harmful tensile residual stress and even generate the beneficial compressive residual stress, due to the volume expansion of low temperature martensitic transformation. This paper briefly describes the mechanism and research of the formation of residual stress related to LTT weld filler.

Keywords: LTT alloy; Phase transformation; Residual stress

Introduction

One of the major problems in welded structures is the welding residual stress (WRS) caused by the inhomogeneous temperature. Many studies have proved that it is detrimental to structural integrity especially when there exist tensile residual stresses [1]. Kannengiesser et al. [2] and Murakawa et al. [3] mentioned that the tensile WRS has a great effect on the crack resistance and the service load. Ohta et al. [4] reported that the additional tensile WRS weaken the fatigue performance of welded joints. On the contrary, compressive WRS can refine martensitic grain and improve fatigue performance of weld joints [5,6]. Therefore, how to control tensile WRS or even introduce compressive WRS to the weld is of significance to improve the integrity of weld structures.

Various conventional methods such as mechanical means (e.g., shot peening, grinding and vibration aging) and post-welding heat treatment are available for re-modifying the state of WRS in welds [7-9]. However, these techniques are cost intensive and time consuming, or even inappropriate for large-scale and inaccessible weld components. The low transformation temperature (LTT) weld filler as a novel technique to mitigate the tensile WRS was introduced in this paper, which can utilize the metallurgical characteristics.

Theoretical Basis of LTT Alloys

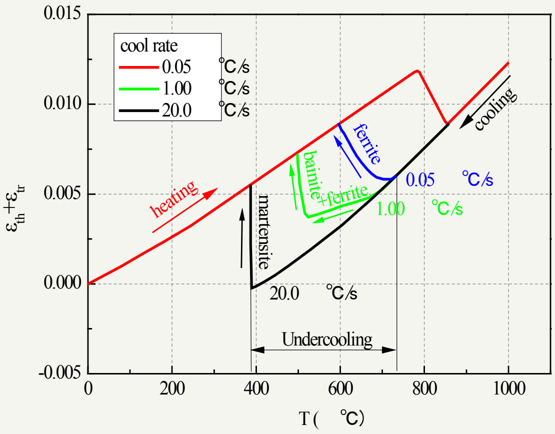
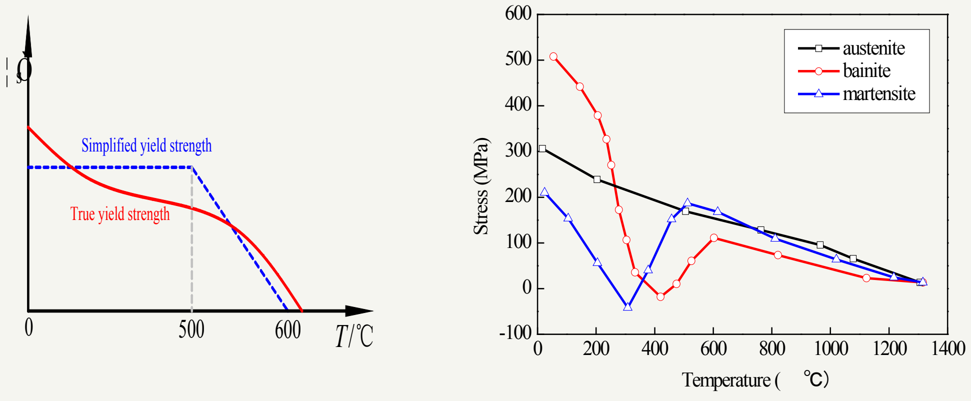


Figure 1: Illustration of internal stress evolution during heating/cooling.

Depending on the chemical composition and cooling rate of the austenitizing area, the austenite decomposition can be divided into two categories: diffusional transformation and displacive transformation. The former is ferrite or pearlite transformation at high temperature, while the latter is bainitic or martensitic transformation at low temperature [10], as illustrated in Figure 1. Due to the difference in the lattice type and the thermal expansion coefficient between austenite (face-centered cubic, FCC) and its decomposition phase (body-centered cubic, BCC), the volume expansion caused by phase transformation would be emerged [11,12]. Nevertheless, the diffusional transformation has a slight effect on the evolution of WRS. Because the phase temperature is higher than the plastic temperature of the alloy material, resulting in the volume expansion converted into plastic deformation. Figure 2 shows that the strain caused by the martensitic transformation is the backbone to offset the shrinkage-related stresses. Thus, the martensitic transformation shows an obvious advantage for controlling the tensile residual stress. Nitschke et al. [14] concluded that martensite is the most appropriate microstructure for stress reduction. Notice that the WRS would accumulate subsequently in the range from transformation finish to ambient temperature.



(a) **(b)**

Figure 2: Schematic illustrations of the (a) yield strength variation and (b) evolution of stresses during cooling of austenite, bainite, and martensite after [13].

The LTT alloys exhibited a low Ms temperature, which is fully exhausted during cooling to ambient temperature and does not sacrifice mechanical properties. Unfortunately, some LTT alloys reduce Ms temperature by increasing carbon content, resulting in low fracture toughness [15]. Shirzadi et al. [16] solved this problem by employing other less detrimental composition to reduce Ms.

Applications of LTT ‘Smart’ Alloys to Reduce Residual Stress

In recent years, the investigation of the residual stress in the LTT weld was studied by many researchers. Ohta et al. [17] compared the residual stress of the LTT and conventional welding consumables by finite element simulation. The results show that the compressive residual stress occurs at the weld joint with the LTT filler. Moat et al. [18] and Lixing et al. has also proved the same conclusion that the longitudinal residual stress show a significant shift from tensile to compressive stresses due to martensitic transformation [18,19]. The Satoh test indicated that the residual stress would decrease with the decrease of the martensitic transformation temperature of the LTT weld metal [20].

In the recent decades, numerous computational approaches have been developed to describe the solid-state phase transformation kinetics. Yamamoto et al. [21] described the mechanism of reducing residual stress (LTT weld) by simulation and measurement. The studies of Murakawa et al. [3,8] showed that the compressive residual stresses primarily depended on the transformation temperature range. Our previous study indicated that the higher Ms temperature introduces tensile stress in the weld zone due to uninterrupted cooling shrinkage, and the inter-pass temperature has a great effect on the state of the RS in the multi-pass LTT alloy welds [22]. If the inter-pass temperature is lower than Ms, the longitudinal tensile stress is generated in the weld except the last weld due to the tempering effect. If inter-pass temperature is higher than Ms, the whole weld bead is entirely in compression.

Conclusion

It has been widely recognized that the low temperature phase transformation has a significant effect on the evolution of residual stress; the LTT ‘smart’ alloy utilizes this effect to mitigate the tensile residual stress. The application of LTT alloy effectively improves the state of residual stress in high strength alloy steel. The LTT alloy is still at the stage of development, a large number of practical problems need to be solved, such as material mismatches and mechanical performance requirements.

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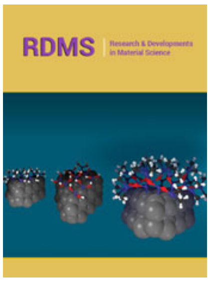

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