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Effect of Titanium on Temper Embrittlement in 2.25cr-1mo Steel Weldment

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Abstract **2.25Cr-1Mo are creep resistant used in boilers, pressure vessels and heat exchangers. Temper embrittlement is the predominant problem in these steels upon exposure at high temperature (400-600°C) for prolonged duration. This is due to segregation of specific impurities in the steel, which segregate to prior austenite grain boundaries. The main embrittling elements are antimony, phosphorous, tin and arsenic. Temper embrittlement also occurs as a result of isothermal holding of a material in that particular temperature range. In the present work, the effect of Titanium on temper embrittlement was studied and by developing SMAW electrode with varying Ti wt%. As-welded samples are subjected to post weld heat treatment and step cooling to analysis the effect of Titanium on temper embrittlement. The sample with higher Titanium wt% displayed beneficial effect on toughness in post weld heat treated and step cooled samples. This is due to the formation of Titanium Carbide precipitation along the grain boundaries which in turn mitigate the segregation of tramp elements.**

Keywords — Temper embrittlement, grain boundary segregation, step cooling, impact toughness, 2.25 Cr-1 Mo steel, Post Weld Heat Treatment, Transition temperature

I. INTRODUCTION

2.25%Cr- 1% Mo is a low alloy steel used in the manufacturing of components for the petroleum and electrical power generation industries. These steels are usually tough and ductile at low temperature and retain good strength at high temperatures [1-3]. During service at 350-550oC this steel exhibits cracking in weld metal possibly due to temper embrittlement as a result of segregation of various tramp elements which are already existing in the steel. Antimony, Phosphorous, Tin and arsenic present as impurity segregates to prior austenite grain boundaries during embrittling treatments and contributes to temper embrittlement of a Cr- Mo steel [4-5].

The impurity element segregation reduces the grain boundary cohesive strength of the material. If segregation reduces the grain boundary strength, it will also affect the carbide/matrix interface strength [5]. The desired microstructure for exhibiting good toughness is a combination of bainite with acicular ferrite as they provide very good toughness also high strength [6]. Temper embrittlement originates as a result of Intercrystallite internal absorption of phosphorus in competition with enrichment of the grain boundaries with carbon, and the role of the alloying elements reduces to affecting the competition between C and P by changing the thermodynamic activity of carbon in the solid solution.

In the present work, the effect of Titanium on temper embrittlement in 2.25Cr-1Mo steel weldment was studied. SMAW welding electrodes with varying Ti wt% was produced and as welded samples are subjected to heat treatment and step cooling treatment to analysis the effect of Titanium on weld toughness.

II. MATERIALS AND METHODS

Rutile coated SMAW electrodes conforming to E9013-G with varying Ti wt% were produced using the pilot electrode extruder facility. The chemical composition of undiluted weld metal for the electrode trials is shown in the Table 1.

Table 1: Chemical composition of undiluted weld metal

Electrode trials	Elements in wt%							
	C	Mn	Si	Cr	Mo	Ti	S	P
Ti-1	0.08	0.71	0.31	2.3	1.15	0.008	0.001	0.002
Ti-2	0.09	0.65	0.25	2.1	1.12	0.026	0.001	0.002

Test coupons were prepared as shown in figure. Preheat temperature is maintained in range of 325°C to 375°C and interpass temperature is maintained in range of 160°C to 190°C. The welding current and voltage were 160 A and

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25 V respectively. Base metal used is ASTM A387 grade 22 steel. Welding is performed in flat position using DCEP current as specified in AWS A5.5/5.5M. One set of as-welded samples are subjected to post weld heat treatment. During post weld heat treatment, the samples are annealed at 690oC. Other set of as-welded samples are subjected to step cooling treatment as shown in the Figure 2.

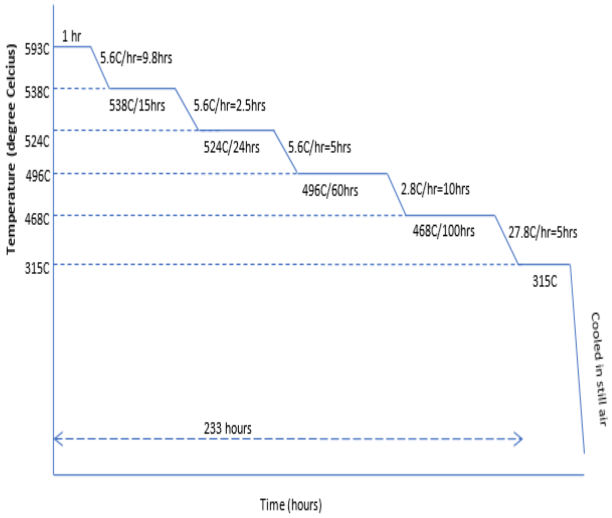

Figure 2: Step cooling heat treatment.

After heat treatment, the samples are characterized using optical microscopy and SEM for microstructural analysis. Charpy impact test was carried out as per ASTM E23 to determine the weld toughness at room temperature and sub-zero temperature. Fractured surfaces are analyzed using Scanning Electron Microscope to determine the type of fracture.

III. RESULT AND DISCUSSION

A. MICROSTRUCTURAL ANALYSIS:

The microstructure of the post weld heat treated and step cooled samples are shown in Figure 3(a-d). The PWHT samples show Bainite with Ferrite microstructure. Sample Ti-2 with higher Titanium wt% displays finer bainite lath with average hardness of 310 $HV_{0.5}$. Average hardness of sample Ti-1 is 295 $HV_{0.5}$. Slightly higher hardness in sample Ti-2 is due to grain refinement and formation of acicular ferrite. Randomly oriented lath like acicular ferrite contributes to higher hardness and toughness [9]. Titanium is the effective grain refiner and it also influence the formation of acicular ferrite by providing the nucleation site. Titanium oxide inclusion is an effective nucleation site for acicular ferrite formation.

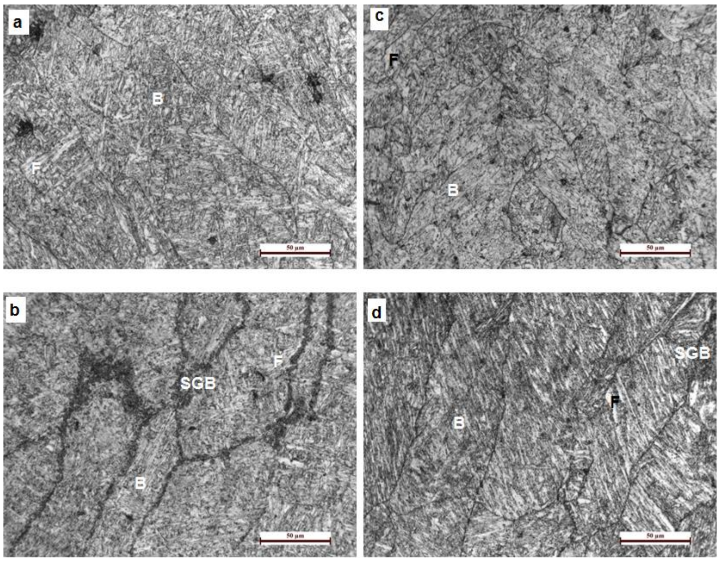

Figure 3: a-PWHT sample Ti-1, b-Step cooled sample Ti-1, c-PWHT sample Ti-2, d-Step cooled sample Ti-2 (B-Bainite, F-ferrite, SGB-Segregated Grain Boundaries)

In case of step cooled samples, microstructure reveals coarse bainite structure with polygonal ferrite (Figure b and d). Slow cooling has resulted in grain coarsening and formation of polygonal ferrite. Step cooling promotes the decomposition of retained austenite into ferrite and carbides. Further slow cooling will result in the segregation of tramp elements such as S and P along the grain boundaries. The average hardness of step cooled Ti-1 and Ti-2 samples are 275 and 310 $HV_{0.5}$ respectively.

In sample Ti-2, no significant change in hardness was observed. The softening effect due to ferrite formation was compensated by the metal carbide formation [2]. Fine dispersed carbide is seen in the microstructure of the step cooled sample of Ti-2. However, in the sample Ti-1 with lower Ti Wt%, slight decrease in hardness was observed compared to PWHT sample. This decrease in hardness was due to carbide coarsening as observed in the SEM micrograph (Figure 4a).

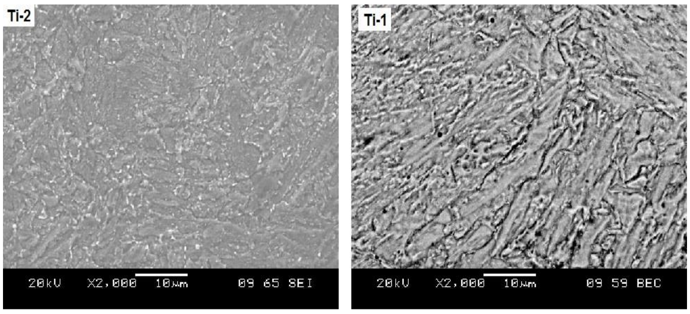

Figure 4: SEM micrograph of step cooled samples

B. TOUGHNESS ANALYSIS:

In correlation to microstructural analysis the PWHT samples display higher toughness then the step cooled samples (Figure 4 and 5). Among the PWHT samples, sample Ti-2 displays higher toughness due to the presence of acicular ferrite and grain refinement effect of Titanium. However at -40 ^{0}C both samples exhibit similar toughness as the samples were tested below the DBTT. Above DBTT, higher Ti content shows beneficial effect on toughness behavior of the material.

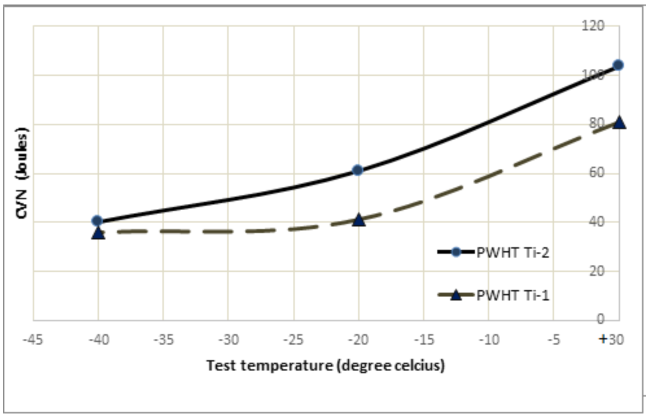

Figure 4: Impact toughness results of PWHT samples

In the step cooled samples, toughness value decreases at par with PWHT samples. As slow cooling induces grain boundary segregation of tramp elements, material toughness decreases and DBTT of material increases. In both the samples Ti-1 and Ti-2, DBTT increases due to formation of embrittling phase formation. However, in sample Ti-2, higher Ti contribute to lower embrittlment as the steel forms fine dispersed carbide lowering segregation at the boundaries as well. In sample Ti-1 with lower Ti, carbide coarsening occurs with few grain boundary carbide contributing to lower toughness.

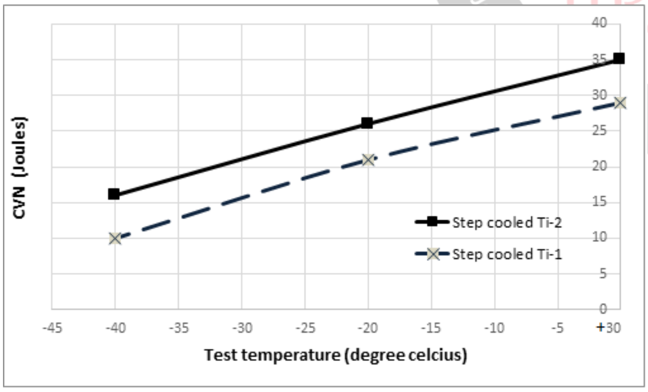

Figure 5: Impact toughness results of step cooled samples

The fractography analysis of the fracture sample is shown in Figure 6. The PWHT samples with higher Ti display ductile type of fracture with dimple structure in room temperature and sub-zero temperature testing. However, in samples with lower Ti display ductile fracture and quasi-cleavage fracture at room temperature and sub-zero temperature respectively. These results display good correlation with microstructure and toughness behavior of the material.

In step cooled samples at room temperature testing, samples show quasi-cleavage fracture due to reduce toughness. Samples tested at sub-zero temperature display predominantly brittle fracture. However, in samples with higher Ti, display less cleavage features due to presence of fine dispersed precipitates throughout the sample which in turn reduce the grain boundary embrittlement compared to samples with lower Ti.

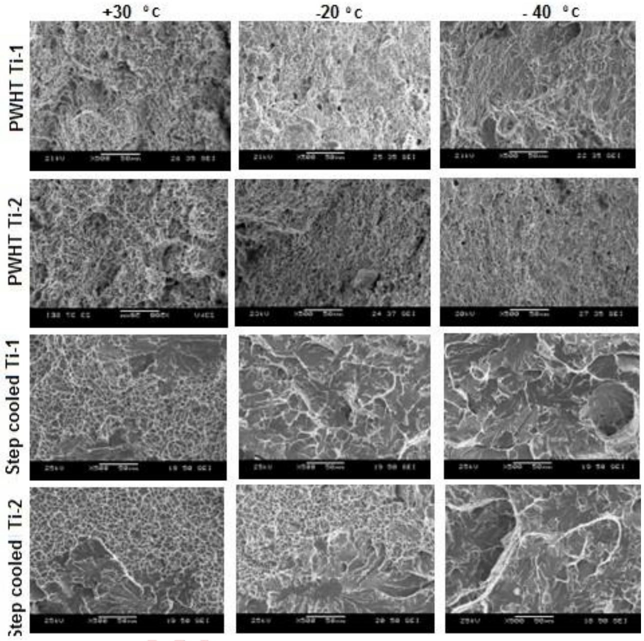

Figure 6: SEM micrograph of impact fracture surfaces

IV. CONCLUSION

- PWHT samples with higher Ti wt% display higher hardness and toughness due the formation of bainite and acicular ferrite microstructure compared to step cooled samples.
- Step cooled samples display lower toughness compared to PWHT sample as slow cooling induces embrittlement with grain boundary segregation.
- In step cooled samples, higher Ti show beneficial effect on toughness as the fine dispersed metal carbides reduce grain boundary embrittlement at room temperature.
- Irrespective of Ti wt% step cooled samples exhibit lower toughness with cleavage fracture at sub-zero temperatures due to higher transition temperature leading to temper embrittlement.

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