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Influence of Steel Melting Processes on Tensile Properties of 14Cr-15Ni-Ti Stainless Steel

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Abstract. A titanium-modified 14Cr-15Ni-2Mo austenitic stainless steel, known as alloy D9, has been chosen as the material for the fuel cladding and hexagonal wrapper of the Prototype Fast Breeder Reactor presently under construction at Kalpakkam. The alloy is generally produced by double vacuum melting process consisting of Vacuum Induction Melting (VIM) followed by Vacuum Arc Remelting (VAR). An alternate route consisting of vacuum induction melting followed by electro slag refining (ESR) has been employed to produce the alloy with lower inclusion content Tensile studies were carried out at various temperatures between ambient and 1023 K at an interval of 50 K and strain rate of 1.2×10^{-3} s^{-1} on the steels in 20% coldworked condition. Tensile properties of both VAR grade and ESR grade material were found to be similar. The influence of the secondary processing routes on the mechanical properties of alloy D9 is studied.

Keywords. Austenitic stainless steel, VAR, ESR, inclusion, strength ratio.

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1 Introduction

Core materials in fast breeder reactors are subjected to a high dose of energetic neutrons which lead to profound changes in physical and mechanical properties [1]. One primary form of radiation damage is the displacement damage in which atoms are knocked out from their normal lattice positions producing vacancies and interstials. The important phenomena arising out of irradiation defects is the change in dimensions generally referred as void swelling, irradiation creep and embrittlement. The mechanical stability of the core components is profoundly affected by this phenomena. Extensive studies have been carried out to determine the influence of chemical composition and microstructure on the void swelling behaviour of austenitic stainless steels [2]. Compositional adjustment of AISI type 316 stainless steel in terms of decreasing Cr and increasing Ni, led to the development of a 14Cr-15Ni-2Mo steel designated as Alloy D9. Coldwork and grain size refinement were also found to be effective in suppressing swelling [3]. Considering the elevated temperature service and influence of irradiation induced stresses, high temperature mechanical properties are essential to be studied. As the alloy constitution profoundly influences tensile behavior, two different methods of refining were chosen and comparative study is made.

During the primary melting of the steel, gases absorbed by the liquid steel from the atmosphere and from process materials can be detrimental to properties of the solid ingot. Oxygen and nitrogen in the steel combine with impurities and alloying elements to form oxides, nitrides, or carbonitrides that remain as inclusions [4]. In VAR method, trapped gases and vaporized nonmetallic inclusions are drawn off by the vacuum. But ESR method being open to atmosphere is not as effective as VAR, in the removal of gases such as oxygen and hydrogen. However it is more effective in decreasing the inclusion content in view of the close contact between molten steel droplets and the flux. Vacuum arc remelting greatly improves the cleanliness of the steel. Inclusions in VAR steel are confined to a few, very small, well dispersed sulphides and/or round oxides, with rare occurrences of silicates. ESR does improve the cleanliness of the steel, but micro inclusions are not removed to the extent of VAR. Slight improvements in the chemical homogeneity of ESR over VAR ingots are caused by the slower melt rate possible in ESR. The objective of the present study is to compare the influence of steel melting practices on the tensile properties of alloy D9 stainless steel.

2 Experimental

A forged bar of ESR grade alloy D9 stainless steel was produced following primary melting by vacuum induction melting and secondary refining by electro slag refining of the VIM ingot. The ESR ingot was hot forged and subsequently tested for absence of defects by ultrasonic method. The chemical composition of the material is given in Table 1. The forged round bar had dimension of 285 mm di-

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ameter and 630 mm length. The bar was cut to machine rods of 20 mm diameter and 200 mm length. These rods were cold worked to 20% by tensile pulling using a tensile testing machine. Cold working was carried out at a strain rate of 6.7×10^{-4} s^{-1}. The VAR grade material used in this study was 20% coldworked hexagonal wrapper tubes of size 131.3 × 3.2 mm produced by double vacuum melting consisting of VIM and VAR melting process followed by cold drawing of the tubes. Tensile samples were fabricated from 20% coldworked hexagonal wrapper tubes. The grain size measured in case of ESR steel is 67 μm and that of VAR steel is 25 μm. Tensile tests were conducted at ambient temperature and in the temperature range 523–1023 K at an interval of 50 K at a strain rate of 1.2×10^{-3} s^{-1}. The test temperature was controlled within ±2 K. Microstructural characterization was carried out by standard metallographic practice using 60% nitric acid solution as etchant.

Element	ESR grade	VAR Grade
Chromium	13.58	13.88
Nickel	15.12	15.24
Manganese	1.9	2.12
Molybdenum	2.24	2.12
Carbon	0.04	0.045
Titanium	0.23	0.23
Phosphorous	0.005	< 0.005
Sulphur	0.003	< 0.005
Silicon	0.71	0.64
Cobalt	0.007	0.007
Vanadium	0.02	< 0.01
Copper	0.012	0.017
Aluminum	0.018	0.01
Arsenic	< 0.0005	0.0019
Niobium	< 0.02	< 0.005
Tantalum	0.02	< 0.01
Boron	< 0.001	12 ppm
Nitrogen	< 0.038	0.0021
Iron	Balance	Balance

Table 1. Chemical Composition of ESR and VAR Grade Alloy D9 SS (in wt %).

3 Results and Discussion

In the following sections, tensile properties of VAR and ESR grade alloy D9 stainless steels are presented and discussed. Figures 1(a) and (b) are the EDAX (Energy-Dispersive X-ray Analysis) spectrum showing the composition of inclusions in ESR grade steel and VAR grade steel respectively. Presence of TiS inclusions can be seen in the EDAX spectrum. Figure 2(a) shows the micrograph of fractured surface and Figure 2(b) is the EDAX spectrum showing titanium inclusions in VAR grade stainless steel.

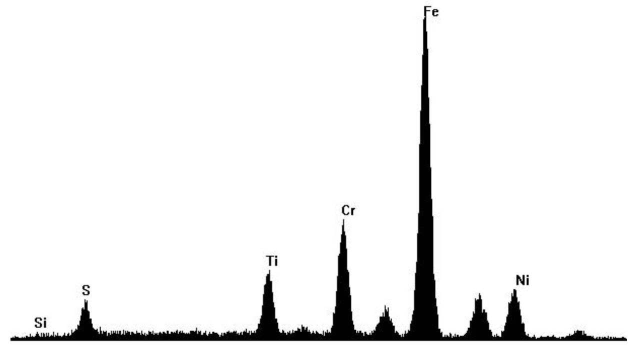

Figure 1(a). EDAX spectrum showing the composition of the inclusions in ESR steel.

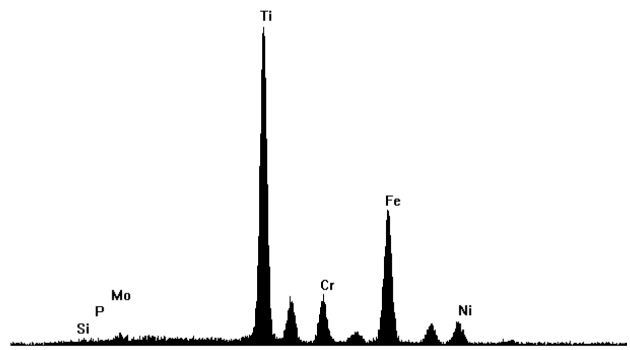

Figure 1(b). EDAX spectrum showing the composition of the inclusions in VAR grade steel.

Table 2 shows the inclusion number and size of the inclusions present in both the steels. The measurement was carried out over an area of 0.5 mm^2. It is observed that VAR grade steel contains less number of inclusions and of smaller size than ESR grade steel.

Sample	Size, μm	Number of inclusions	Size, μm	Number of inclusions
ESR	12	2	8	2
VAR	12	1	8	1.25

Table 2. Inclusion content in VAR and ESR grade stainless steels.

3.1 Effect of Cleanliness on Mechanical Properties

The yield strength and ultimate tensile strength values of ESR grade stainless steel are compared with the properties of VAR grade D9 stainless steel tubes in Figures 3 and

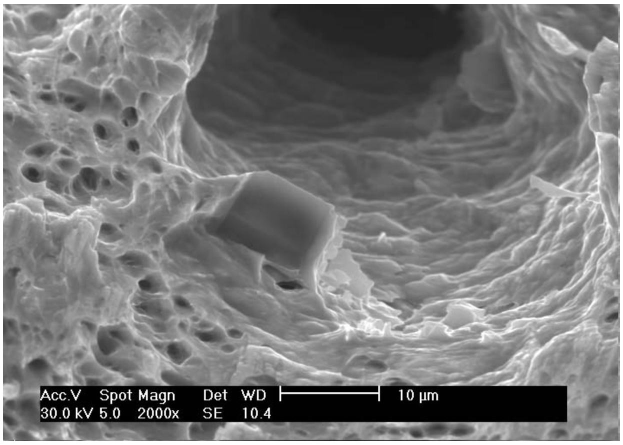

Figure 2(a). Fractograph indicating titanium inclusions.

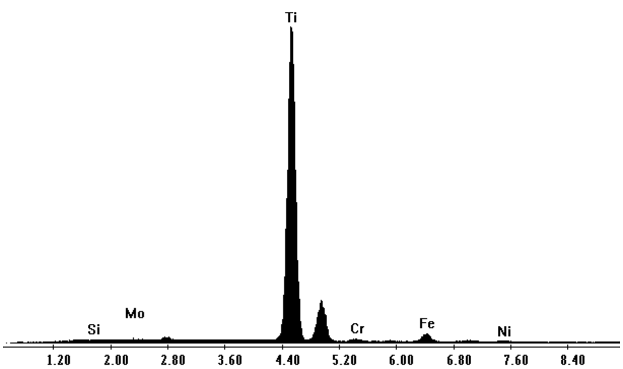

Figure 2(b). EDAX spectrum showing titanium inclusions in VAR grade steel.

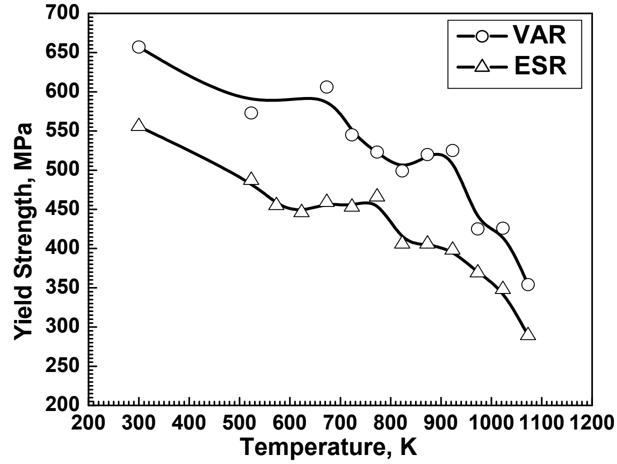

Figure 3. Variation of yield strength with temperature.

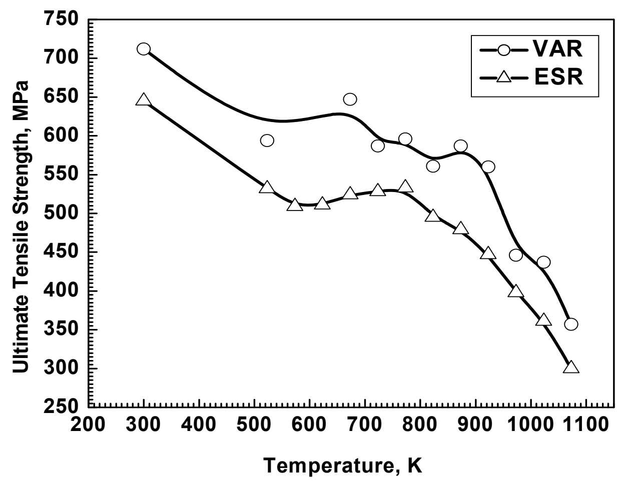

Figure 4. Variation of Ultimate tensile strength with temperature.

4 respectively. It is seen that the yield strength and ultimate tensile strength values of ESR grade material are lower than those of VAR grade tubes. The plot of yield strength against temperature may be divided into three regimes viz. first regime between room temperature and 623 K, the second regime between 623 and 923 K and the third regime beyond 923 K. In the second regime, serrated flow is observed in the load-elongation curves. This phenomenon is often related to dynamic interaction between mobile dislocations and solutes, and is known as dynamic strain ageing (DSA). Other manifestations include peaks in the variation of flow stress, saturation stress, and minimum value in ductility etc., as function of temperature. Hence the serrations found in the flow curve in the intermediate temperature regime is attributed to dynamic strain ageing. The third regime being at higher temperature is associated with rapid decrease in flow stress, work hardening rate and uniform plastic elongation due to dynamic recovery process, leading to early cross slip and climb of dislocations. Similar trend is also observed for the variation of ultimate tensile strength with test temperature.

The ratio of strength of ESR grade material to the strength of the VAR grade material with test temperature is shown in Figure 5. Yield strength values of ESR grade material are about 85% of the yield strength values of VAR grade material, the Ultimate Tensile Strength values are about 90% of the Ultimate Tensile Strength of the VAR grade material. This shows that there is a little influence of differences in cleanliness on the strength values of the steel [5].

The variation of uniform elongation with temperature for ESR and VAR grade material is shown in Figure 6(a). ESR grade steel shows higher uniform elongation than VAR grade steel. This is due to improvements in the chemical homogeneity of ESR over VAR ingots due to the slower melt rate possible in ESR. Figure 6(b) shows the variation of total elongation with temperature of the ESR grade material and the VAR grade material. The ductility values of ESR grade material are higher than the values of the VAR grade material in the temperature range 523–723 K. The lower ductility of ESR grade stainless steel is attributed to the for-

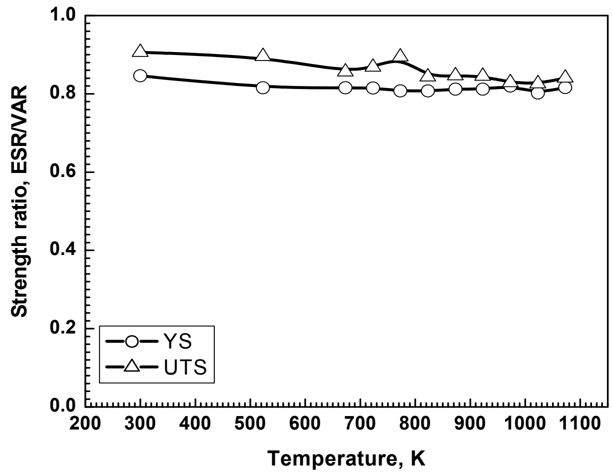

Figure 5. Variation of strength ratio with temperature.

mation of sulfide inclusions which are classified as Type II inclusions according to ASM Handbook [6].

4 Conclusions

- There is little influence of differences in cleanliness on yield strength and tensile strength of the alloy.
- The ESR grade stainless steel shows a higher uniform elongation than VAR grade stainless steel due to improvements in chemical homogeneity. The lower ductility values of ESR grade stainless steel are due to the presence of Type II inclusions.

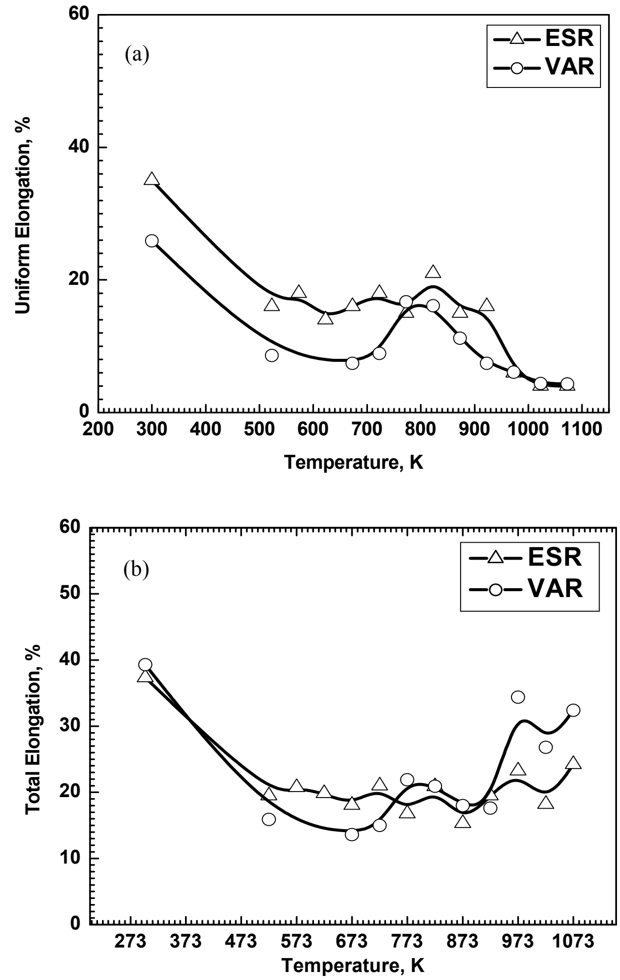

Figure 6. Variation of (a) uniform elongation and (b) total elongation with temperature.

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