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EFFECT OF MELTING PROCESSING ON TENSILE PROPERTIES AND MICROSTRUCTURE OF NEW RAFM STEEL

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ABSTRACT

All of the RAFM steels only safely used under 550 ℃, that is not enough for the next reactor. An new RAFM steel was melted by non-vacuum induction melting (VIM) and electro-slag remelting (ESR), followed by hot-forging and rolling into rods and plates. In this paper, we investigated the effect of thermal ageing treatment on tensile properties of the rods and plates. The microstructure was studied by OM (optics micrograph) and scanning electron microscopy (SEM). The results showed that by using the same heat treatment process, the tensile strength of the samples was 680MPa, the total elongation was 31%, which were better than the CLAM steel whose tensile strength and total elongation were 668MPa and 25% respectively. The difference between the transverse and the longitudinal properties was reduced markedly. So the ESR played an important part in improving the mechanical properties.

KEYWORDS:

RAFM; electro-slag remelting; thermal ageing treatment; tensile properties

1. INTRODUCTION

Reduced activation ferritic/martensitic (RAFM) steels are one of the candidate first-wall and blanket structural materials for both ITER test blanket modules, the demonstration fusion power plant (DEMO) fusion reactor and future fusion power systems in essentially all of the worldwide fusion materials research programs because of their better swelling resistance, thermo-physical and thermo-mechanical properties, as compared to austenitic stainless steels [1, 2]. Research on RAFM steels has been carried out in ITER parties (Europe, Japan, Russia , USA and China) [3] in the past years and some inspiring progress has been made, including the development of F82H, JLF-1, EUROFER97, T91, HT9 and CLAM steels [4,5,6,7]. However, the temperature window for use of RAFM steels is presently about 350-550 ℃, the lower value being limited by irradiation-induced embrittlement effects and the upper value by a strong reduction in mechanical strength. Most of these steels were melted by vacuum-induction-melted [8,9,10,11].

The Electro-Slag Remelting（ESR）method [12] is an effective remelting process in eliminating oxide and sulphide inclusions in steel. So in order to get extra-low levels of sulphur and oxide, the ESR method was used for secondary refining. In this, the steel to be refined is made in the form of a cast of rolled bar and is progressively melted by immersing its lower end in a resistance heated bath of molten superheated slag held in a water-cooled copper or mild steel mould. Steel processed through ESR possesses improved cleanliness, fatigue resistance, fracture and notch toughness, ductility, weld ability, corrosion resistance and isotropy in properties [13, 14,15].

In this paper, the new RAFM steel is melted by non-vacuum induction melting (VIM) and electro-slag remelting (ESR) , the tensile properties and microstructure of bar and plants are reported .

2. EXPERIMENT PROCEDURES

Specimens used in this study were new RAFM (Fe-9Cr-0.11V) martensitic steel. Chemical compositions of the specimens are given in Table 1.The new RAFM steels was melted by non-vacuum induction melting (VIM) and electro-slag remelting (ESR), followed by hot-forging and rolling into rods and plates. Subsequently, the hot-rolled rods and plates were thermally treated to produce a fully tempered and fine-grained martensitic microstructure without any retained austenite. They were quenched at 980 ℃， water-quenched, and tempered at 760 ℃, then underwent air-cooling.

Smooth cylindrical specimens, 57.5 mm in length, and with a 25 mm gage length and 5 mm gage diameter, were machined from the heat-treated round rods in such a way that the gage section was parallel to the longitudinal rolling direction. Also two specimens were machined from the transverse and the longitudinal of the plates, respectively.

Table 1
Chemical compositions of the new RAFM steels (mass%).

Element	Fe	Cr	C	Mn	Si	Ni
Content	Bal	8.85	0.12	0.50	0.12	0.06
Element	Cu	W	Mo	V	P	S
Content	0.03	2.16	0.01	0.11	0.019	0.005

After the heat treatment, microstructure was investigated by optical microscopy (OLYMPUS PMG3). The tensile property tests were performed at room temperature by using a computer-controlled mechanical testing system in air, with loading rate of 5×10^{-5}m/s. Fracture surfaces of the tensile specimens were analyzed by means of scanning electron microscopy (ESEM Quanta 200) enabling to recognize fracture mechanism and determine the extent and morphology of failure.

3. RESULTS

3.1 Tensile results

The tensile specimens were tested at room temperature. The results for rods and plates of new RAFM steel are shown in Figure 1 and Table 2. An examination of these figures clearly indicates that the magnitude of the yield strength (YS), ultimate tensile strength (UTS), elongation and failure strength (σ_s) gradually similar. The ultimate tensile strength is 680MPa, the failure strength is 410 MPa, the elongation is 31% and the reduction of area is 66%.

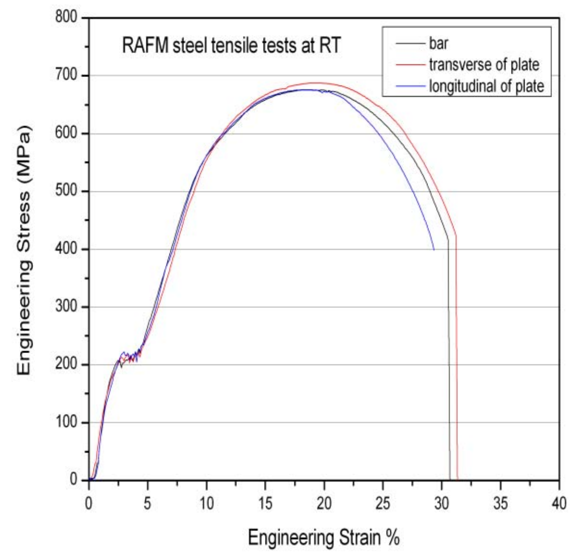

Figure 1. Tensile curves (engineering stress and strain) of new RAFM steel.

Table 2
Reduction of area of different part of RAFM steel.

Matetial	bar	transverse	longitudinal
Reduction of area (%)	65.94	66.35	66.34

3.2 Microstructure

The optical micrographs of the new RAFM steel, quenched and tempered for 2 h, are illustrated in Figure 2, and show a fine-grained, tempered, martensitic microstructure. Streaks of martensitic laths oriented in different directions were also visible within the finely dispersed martensitic structures, possibly due to the positioning of metallographic mounts that were different from the rolling direction. The martensite laths that colonized the prior austenite grain（PAG）during the air cooling from the normalizing temperature 760℃. The average PAG size is approximately 14μm. For the bar, the transverse and longitudinal of the plates, the PAG size is essentially the same. Similar microstructure characteristics were observed with different parts of new RAFM steel.

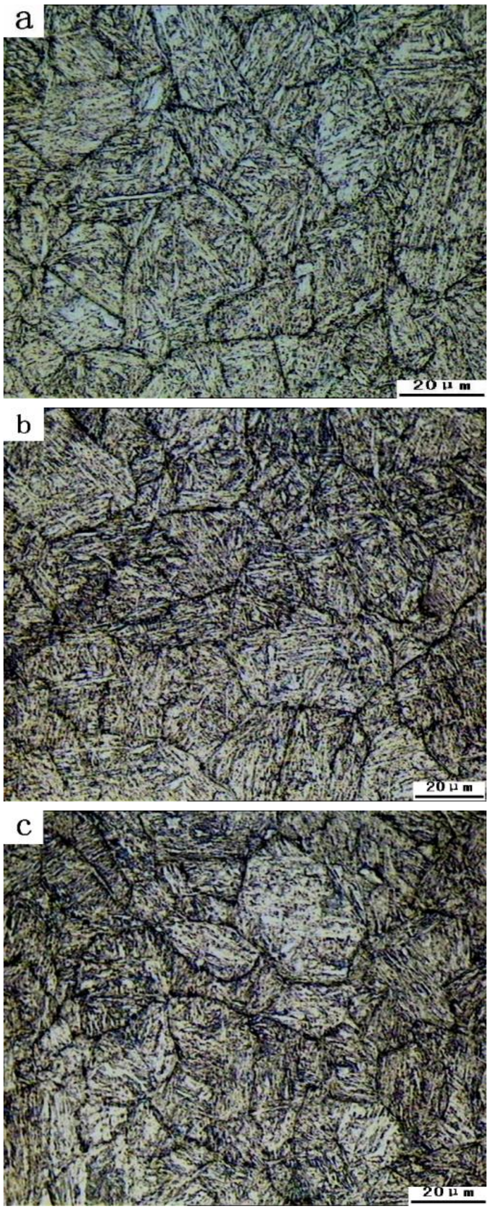

Figure 2. Optical micrograph of new RAFM steel :(a) bar ; (b) transverse; （c）longitudinal.

3.3 SEM

The results of the SEM study of the primary fracture surface of the new RAFM steel at different parts are illustrated in Figure 3. An examination of these micrographs revealed combined ductile (dimples) and brittle (intergranular cracking) failures. In figure 3, there are a number of small dimples (the diameter is ≤ 5μm) and few microcrackes that developed at room temperature. So, the plasticity, characterized by reduced cracking and dimpled microstructures, indicating better ductility, the elongation strain of the specimens is about 31%. Also there contain some narrow- holes that is pulled out of the martensite laths from matrix, that is mean the forced direction parallels the martensite laths. Figure 3 (a) and (c) have more than figure 3 (b). So the bar and longitudinal specimens have lower tensile strength than transverse specimen, the tensile strength of bar, longitudinal and transverse specimens are 675.67MPa, 676.18MPa and 687.89MPa, respectively.

4. DISCUSSION

In Figure 1 and Table 2, the tensile properties of bar and plates are isotropy and better than many of the RAFM steel [16], that is the reason of remelted by electro-slag remelting and changed some alloy elements. Firstly, the ESR process reduced the content of sulphur and phosphorus which is harmful in steel [17]. In table 1, the sulphur is 0.005% and the phosphorus is 0.019%. Steel processed through ESR possesses improved cleanliness, fracture and notch toughness, ductility and isotropy in properties. Secondly, in table 1, the RAFM steel contains 0.11%V and 2.16%W. V played a major role on the grain refining. Namely, V and C, N form a V-rich carbides and nitrides, pinning the original austenite grain boundaries and prevent grain growth and thus play a role in grain refinement in the solution treatment time. In the tempering treatment, V in the form of carbides precipitation dispersion within or between the martensite laths, these non-cut spherical precipitates could impede dislocation movement, stabilize the martensitic lath structure, and thus played a certain role in strengthening and toughening the matrix. At the same time, W is to improve the strength of martensitic steel elements, can further improve the experimental RAFM steel mechanical properties.

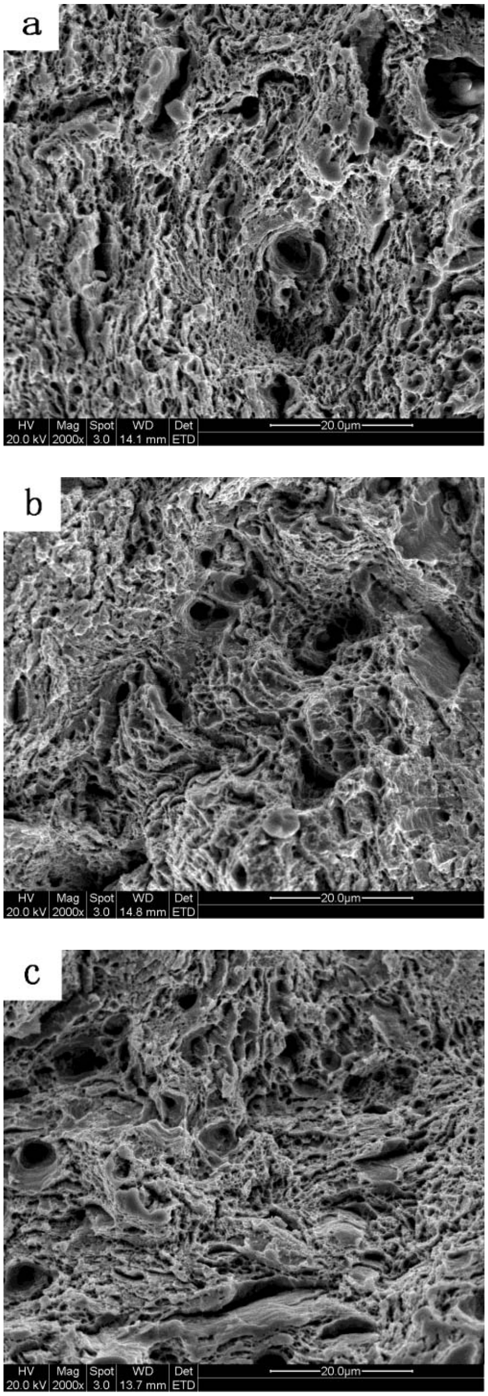

Figure 3. SEM of new RAFM steel :(a) bar ; (b) transverse;（c）longitudinal.

5. SUMMARY AND CONCLUSIONS

The bar and plate tensile properties of the new martensitic steel RAFM was evaluated at room temperature. The metallographic and fractographic evaluations of the alloy was performed using optical microscopy and SEM. The significant conclusions derived from this investigation are summarized below:

·The new RAFM steel contain extra-low levels of sulphur and phosphorus, the sulphur is 0.005% and the phosphorus is 0.019%.

·The magnitude of the ultimate tensile strength is 680MPa, the failure strength is 410 MPa , the elongation is 31% , the reduction of aera is 66%, and the different parts of the new RAFM steel showed significant similar properties at room temperature.

·The optical micrograph of the new RAFM steel is tempered martensitic microstructure.

·The morphology of failure was characterized by plastic deformation at room temperature. Microcrack and dimple microstructures were observed on the fracture surfaces.

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