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Microstructure and Mechanical properties of Y_2O_3-Strengthened Fe-Cr Alloy Castings for High Temperature Applications

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The oxide dispersion strengthenened alloy (ODS), MA956, is an ideal candidate in sulfur containing high temperature environments. This alloy is an iron-based alloy prepared by adding Y_2O_3 via powder metallurgy. The challenge is to produce an alloy close to MA956 by casting technology. This is because Y_2O_3 which has lower density than steel floats on the surface of the melt and accumulate in the cast riser. In the current work, a 20% Cr-Fe alloy strengthened by 0.5% Y_2O_3 was fabricated through casting process. The microstructure and mechanical properties of this alloy after casting and heat treatment were investigated. Energy dispersive spectrometry (EDS) showed some randomly distributed particles containing Y. The tensile strength was doubled after forging and heat treatment of the cast alloy. These results confirmed that Y_2O_3 can be added to the steel matrix during casting, which is a more economical and practical method for ODS alloy fabrication.

Keywords: Oxide strengthened alloys, casting, microstructure characterization, mechanical properties.

1. Introduction

High operating temperature, combined with sulfur environment is likely to be encountered in service. This creates a severe operating condition for materials used in high temperatures. In some Egyptian boiler power plants, a sulfur containing fuel was recently used as an alternative in case of shortage in natural gas. In the burner area, where the S containing fuel circulates, the diffusers fail after 6 months of usage as shown in Fig. 1. These diffusers were fabricated of Ni50:Cr50 alloy. The failure analysis showed that formation of Ni-sulfides was the main reason of failure. It was reported that the melting point of Ni-sulfide eutectic (Ni-Ni_3S_2) is as low as 635°C, compared to eutectics of cobalt and iron which are 880°C and 985°C respectively [1,2]. This low melting point sulfide cause voluminous scales and lead to damage. Therefore, an iron–based high

Fig. 1 Diffuser before and after failure.

temperature alloy which resists S containing gases was selected. Alloy MA956, is known for its high-temperature creep resistance in S containing environments [3,4]. However, this alloy is prepared by mechanical alloying followed by hot pressing which is a complicated process. In the current study, a cast alloy close in its chemical composition to MA956 was prepared and its microstructure and mechanical properties were investigated.

2. Experimental work

The charge materials were added as follows; steel scrap, low carbon ferro chromium followed by addition of pure Al metal, and finally Y_2O_3 powder. Melting was done in an induction furnace at 1650 °C. The frequency was controlled to allow the melt stirring in order to prevent the oxide particles from floating on the surface. The chemical composition of the Fe alloy is shown in Table 1. Some cast bars were then forged to distribute the oxide particles and refine the cast microstructure. After forging, the samples were heat treated by normalizing at 1100 °C for 15 minutes. Microstructure investigation and mechanical properties evaluation of the cast, heat treated and forged samples were performed.

Table 1 Chemical composition of the cast alloy.

C	Si	Mn	P	S	Cr	Mo	Ni	Al
0.059	0.51	0.587	0.0187	0.011	18.22	0.0538	0.221	>3.6
Co	Cu	Nb	Ti	V	W	Pb	As	B
0.316	0.074	0.014	0.22	0.0735	0.0149	<0.003	0.005	<0.0001

3. Results and discussion

3.1 Microstructure investigation

Microstructure of the samples was investigated using SEM and EDS. Figure 2 shows the microstructure of the cast and forged specimens before and after heat treatment (HT). The grain refinement of the ferritic matrix due to forging is shown in Fig. 2 (c). Since the elemental yttrium couldn't be analyzed (in Table 1) using the available spectrometer, EDS was used to analyze some particles which were randomly distributed in the matrix as shown in Fig. 3. It is clear that Y_2O_3 could successfully be introduced in the matrix. The amount of added Y_2O_3 was planned to be 0.5%, however the low amount of Y observed by EDS is due to floating of such fine particles during melting.

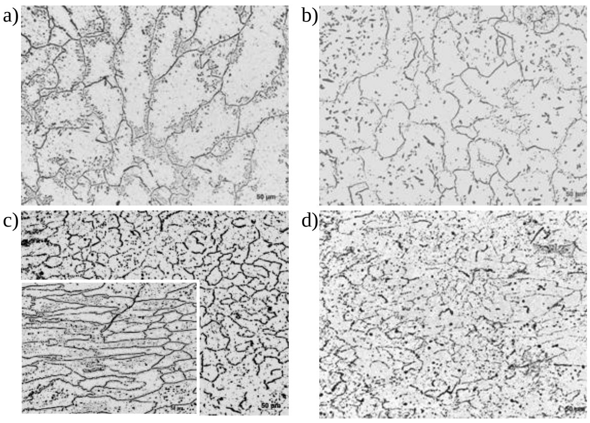
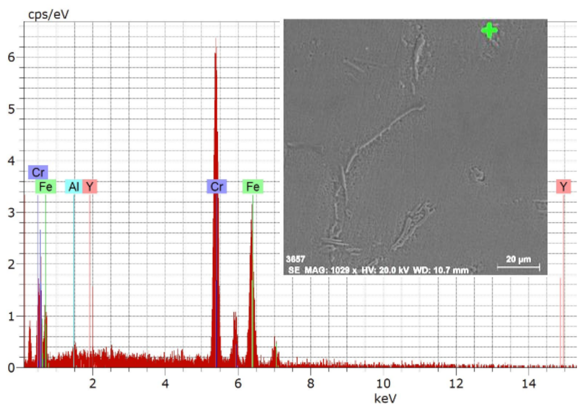


Fig. 2 Microstructure of cast samples (a, b) and forged specimens (c,d) before and after heat treatment respectively.



El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [wt.%]
Cr	24	K-series	36.78	54.84	56.07	1.2
Fe	26	K-series	29.57	44.09	41.96	1.1
Al	13	K-series	0.65	0.97	1.91	0.1
Y	39	L-series	0.07	0.10	0.06	0.1
		Total:	67.06	100.00	100.00	

Fig. 3 EDX analysis of some Y containing particles.

3.2 Mechanical properties

In order to evaluate the properties of this Y_2O_3 added cast alloy, hardness measurements and tensile test were performed, as shown in Table 2. It is observed that the cast samples have low hardness and low ultimate tensile strength as well. After forging and heat treatment, UTS was relatively increased. It was reported that [5], the ferritic steels show lower strength at temperatures exceeding 600°C, but are more resistant to thermal shocks than high temperature austenitic stainless steels. With the thermal conductivity higher and the thermal expansion lower than the respective values for austenitic steels, equal thermal shocks will result in lower thermal stresses in the ferritic material. In these terms, ferrites allow greater tolerances for design and operation . Therefore, the designed alloy in this work is believed to work properly at high temperature and S containing atmosphere.

Table 2 Hardness and tensile strength measurements.

Condition	Hardness, *Hv*	UTS, N/mm^2
As-cast	104	251
Cast-HT	133	310
As-forged	168	316
Forged-HT	251	502

4. Conclusions

The current research showed that Y_2O_3 could be added to the steel matrix during casting process. Subsequent deformation and heat treatment could significantly enhance the mechanical properties of the castings. Further research works are needed to increase the percentage of the oxide dispersions in the steel matrix using casting technology.

Acknowledgements

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