The Research and Application of Vacuum Remelting and Refining of Gas Turbine Blade Materials

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Backgrounds

The blades of gas turbines need to continuously operate under high temperature environments, so a good portion of their materials have to be composed of nickel or cobalt-based superalloys, which are very expensive. Allowing scrapped blades reusable not only maximize the values of recycling economy, but also help to save the operation and maintenance costs of future advanced gas turbines. In this study, we introduce the scrapped moving blades (graded 3rd stage, made of Udimet 500, earlier material of MS7001 E type, decommissioned from a TPC power plant) handed over to TPRI to conduct vacuum re-melting & re-fining related researches.

The scrapped blades were later on remelted in a vacuum furnace (Figure 1) and cast into a self-made graphite mold for cooling and rapid solidification (lifted and stirred by electromagnetic force to form ingots). To enable the ingots to meet the requirements of next generation materials, experiments of component prediction and addition were also carried out to serve as technical reference for future component design.

Fig. 1 Schematic Diagram of Vacuum Melting Furnace

Methods

The contents of this study's 1st round experiments are as follows:

1. evaluating the vacuum melting process,
2. predicting material properties by software,
3. selecting heat treatment receipt,
4. remelting, refining and material test verifications,
5. solution treatment of 1125°C/2hr,
6. solution and aging treatment of 1085°C/4hr+848°C/4hr+760°C/16hr,
7. solution treatment of 1080°C/2hr,
8. solution treatment of 1180°C/2hr,
9. verification experiments:
   (1) GDS (Glow Discharge Spectrometer),
   (2) OM (Optical Microscope),
   (3) SEM (Scanning Electron Microscope),
   (4) Oxygen, Nitrogen, Hydrogen elements analysis,
   (5) tensile test,
   (6) high temperature stress-rupture test,
   (7) other relative tests.

In the 2nd round experiment, Udimet 500 was adjusted to IN738 by means of additive smelting using vacuum melting equipment and composition adjustment, and verified by GDS experiment and oxygen, nitrogen and hydrogen elements analysis.

Fig. 2　The Preliminary Material Calculation Results

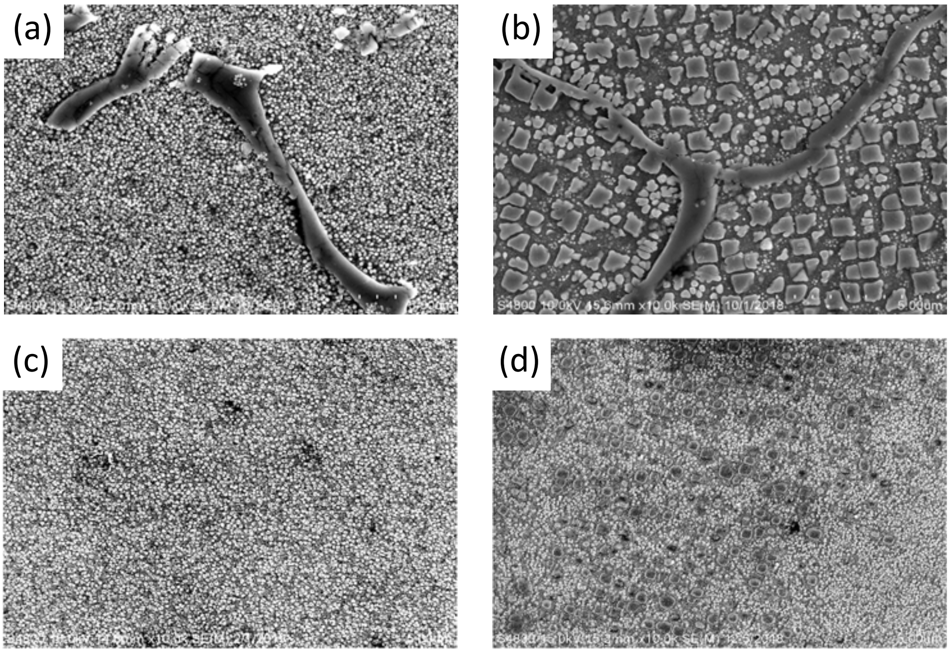

Fig. 3 Microstructure at A Different Temperature of Heat Treatments (a) 1125°C/2hr. (b) 1085°C/4hr + 848°C/4hr + 760°C/16hr. (c) 1080°C/2hr. (d) 1180°C/2hr.

Results

The results of our experiments indicates that the alloy composition of the blades presented varied degrees of burn-out condition due to different melting points. The situation can be solved by developing material calculation software (Figure2) and additive melting. Besides, heat treatments accompanied with our experiments indicated that the ex post tensile properties were superior to the ex ente properties, and the rupture time of the high temperature creep test met and exceeded the EPRI eligibility criteria. With the help of scanning electron microscope (SEM), it was observed that the size of coarse γ' particle, under the condition of 1085℃/4hr + 848℃/4hr + 760℃/16hr, was about 0.5 μm and square shaped, shown as Figure 3. Due to large atomic arrangement mismatch, high strain energy inclined to strengthen the resistance of dislocation movement; when compared with other heat treatment conditions, presented higher strength and poor ductility at room temperature, shown as Table 1. In addition, Udiment 500 had been successfully changed into IN738 by adopting the method of additive material melting, shown as Table 2.

Based on the aforesaid experiments, we have predominated the smelting process and quality inspection methods of Udimet 500, along with the strengthening mechanism and adjustment methods for subsequent heat treatment and mechanical property testing. We are obliged to continuously promote the aforesaid blade recycling technologies and relevant applications to the other TPC power plants in the future. The to-be-saved material costs are estimated at least 1/3 of the new blade prices, not yet counting technology innovation values/benefits of blade refining and resource recycling.

Mechanical Property / Specimen	Width mm	Yield Strength MPa	Tensile Strength MPa	Elongation %

Table 1

A-1	2.04	536	848	17.7
A-2	1.99	728	977	18.1
A-3	1.9	535	881	14.7
A-4	2.2	671	898	16.8
A Average Value		618	901	16.8
B-1	1.99	672	784	5.8
B-2	1.99	652	821	5.9
B-3	1.97	671	835	7.3
B-4	1.98	695	866	9.4
B Average Value		673	827	7.1
C-1	2.02	633	794	11.8
C-2	2.06	600	817	17.2
C-3	2	645	905	16.9
C-4	2.03	576	747	18.8
C Average Value		614	816	16.2
D-1	2.05	609	848	16.7
D-2	2.09	579	779	17.8
D-3	2.02	629	893	16.8
D-4	2.01	535	700	13.5
D Average Value		588	805	16.2

Comparison of Tensile Data at Room Temperature after A Number of Heat Treatments

Table 2 Udimet 500 Changed into IN738 by Means of Additive Smelting.

Prediction of smelting with adjusted components (w. t. %)																			
Element / Specimen	Ni	C	Mn	P	S	Si	Cu	Cr	Fe	Mo	V	Ti	Al	Nb	Co	W	B	Zr	Ta
IN738	61.5160	0.1100	0.0040	0.0020	0.0050	0.0200	0.0070	15.9700	0.0510	1.6970	0.0050	3.3940	3.3940	0.8980	8.4840	2.5950	0.1000	0.0500	1.6970
GDS composition test (w. t. %)																			
Additive Melting Average Value	59.6310	0.1033	0.0198	0.0070	0.0230	0.0571	0.0215	15.6000	0.6078	1.3780	0.0205	3.6670	3.6977	0.8802	9.3220	2.6024	0.0917	0.0640	1.1582