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Discussion on Smelting Technology of Inconel600 Nickel-Ferrochrome Alloy

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Abstract. This paper introduced the smelting process of Inconel600 nickel-ferrochrome alloy by medium frequency induction furnace. The smelting, forging, rolling and drawing process parameters of the alloy are determined by this study. By using nitrogen and oxygen analyzer, direct reading spectrometer, OEM, electronic probe and electronic universal material testing machine, the chemical composition, gas content, inclusions, internal microstructure, mechanical properties and fracture morphology of the trial-produced products were analyzed. The results show that the Inconel600 nickel-ferrochrome product meets the national standard and the comprehensive performance of the product is good.

Keywords. Inconel600, Inconel alloy, nickel-ferrochrome alloy, non-vacuum induction smelting, melting process

1. Introduction

Inconel600 alloy is a nickel-ferrochrome nickel-based solid solution strengthening alloy with comprehensive properties of toughness and corrosion resistance, which is widely used in manufacturing industrial equipment in the field of chemical industry [1], such as heaters, heat exchangers, evaporators, distillation POTS, distillation towers, condensers, etc. Inconel600 nickel-ferrochrome alloy also has high strength and oxidation resistance at high temperature, so it is also used in the manufacture of various structural parts for heat treatment industry [2-6]. The alloy also has corrosion resistance of high temperature and high pressure water, so it is also used in nuclear power industry. The alloy has excellent thermal conductivity, its thermal conductivity is about 11 times that of ordinary nickel alloy, and it is also used in spark plug products [7-10]. This paper focuses on the non-vacuum induction smelting process of Inconel600 nickel-ferrochrome alloy, inconel hot working process parameters and drawing process, and analyzes the chemical composition, internal structure, mechanical properties and fracture morphology of Inconel600 nickel-ferrochrome alloy products.

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2. Inconel600 Alloy Trial Production Process

2.1. The Composition and Process Route

The composition of Inconel600 alloy is shown in table 1.

Table 1. The composition of Inconel600 alloy.

The element	C	Cr	Ni	Fe	Cu	Si	Mn	Ti	P	Ca	S
The adding amount(%)	0.04	15.0	The remaining amount	7.5	-	-	0.6	0.1	-	0.03	-
Reference Standard (%)	≤ 0.15	14.0-17.0	The remaining amount	6.0-10.0	≤ 0.50	≤ 0.50	≤ 1.0	-	≤ 0.030	-	≤ 0.015

Inconel600 alloy process route: raw material → intermediate frequency melting → casting as cast rod → forging → rolling → disk heat treatment → drawing

Air frequency induction furnace capacity is 50Kg, frequency is 2500Hz, the maximum power is 75KW. The main charge is electrolytic nickel, JCR98.5-A, JMn96, micro carbon ferrochrome, nickel and magnesium, silicon calcium block, titanium sponge. The slagging materials are fluorite and quicklime. Deoxidizer is aluminum lime powder and silicon calcium block.

When Inconel600 alloy is smelted by medium frequency induction furnace, in addition to the conventional high alloy smelting process, special emphasis is placed on the deoxidation operation during refining period. Deoxidizer is added in batches during the refining period. After each batch of deoxidizer is added, the slag will react with the deoxidizer for a certain time and then gently dot the slag. Adhere to the principle of small amount, multiple batches and light dot.

Because non-vacuum furnace smelting has no ability to degassing and remove harmful impurity elements, all raw materials needed for non-vacuum smelting must be treated and selected strictly, and various additives are used to eliminate the influence of harmful impurity elements on the properties of alloys.

2.2. Forging and Hot Rolling Process

Forging equipment is 0.5T compressed air hammer. In the preheating stage, the billet is heated from room temperature to 850℃, and in the heating stage, it is heated from 850℃ to forging temperature. At the forging temperature, the billet is kept warm, and the steel is turned frequently to make the temperature uniform. Initial forging temperature >1050℃, final forging temperature >870℃, air cooling.

The rolling mill is a 16-pass deformation process unit, the initial rolling temperature >1000℃, the final rolling temperature >870℃. Air cooling.

2.3. Wire Drawing Process

The model of the drawing machine is LC-ZL615, and the working speed is 75r/min. In the process of drawing, all kinds of silk must be treated with solution, alkali explosion, pickling and high pressure water cleaning. Solution treatment: heating temperature is

1095-1150°C, holding time is 1.5-2.5 hours. Then the aging treatment was carried out at 700-750°C for 15 hours.

3. Inconel600 Alloy Trial Production Results

3.1. Chemical Composition

A lathe was used to remove the oxide skin on the ingot surface, and then the chip was sampled for chemical composition analysis. The ingot was cut into pieces with a band saw machine, and the pieces were cut into φ 4×10 standard samples with electric spark wire cutting machine. The gas content in the ingot was analyzed by nitrogen and oxygen monitoring instrument.

Direct reading spectrometer and nitrogen and oxygen analyzer were used to analyze the composition of Inconel600 nickel-ferrochrome alloy ingot. The results are shown in table 2, and the chemical composition meets the composition requirements. The analysis results of Inconel600 gas content are shown in table 3. S content is low with good deoxidation, O content is around 50ppm, but nitrogen content is slightly higher.

Table 2. Chemical composition of Inconel600 ingot.

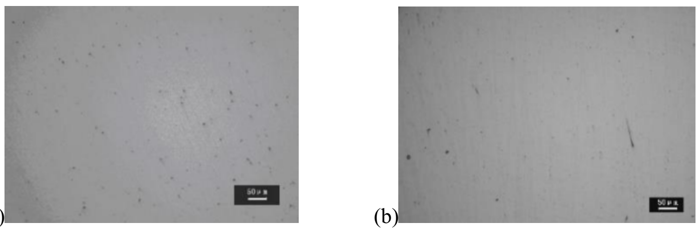
The element	Cr	Fe	Al	Ti	Mn	Si	P
Test results (%)	15.17	7.31	0.045	0.054	0.63	0.13	0.0090
Reference Standard (%)	14.0-17.0	6.0-10.0	-	-	≤1.0	≤0.50	

Table 3. Gas content of Inconel600 nickel-ferrochrome alloy.

The element	S	O	N	H
Test results (%)	0.0010	0.0051	0.020	2.3(ppm)

3.2. Ingot Metallography and Inclusion Analysis

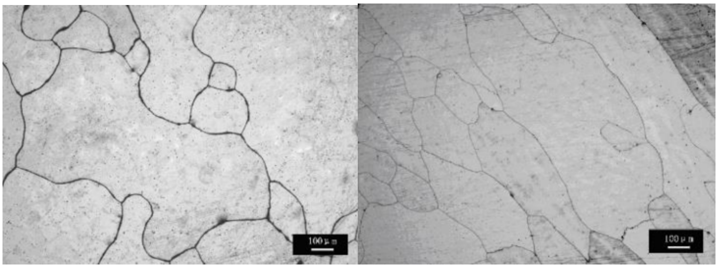
The transverse and longitudinal sections of Inconel600 ingot were sampled by automatic cutting machine, and the metallographic structure, inclusion distribution and microstructure of Inconel600 ingot were analyzed by 2G-200L metallographic microscope and IXA-8800R electron probe. The transverse and longitudinal section morphology of Inconel600 nickel-ferrochrome ingot is shown in figures 1 (a) and (b). It can be seen from figure 1 that there are a small number of scattered point-like inclusions in the cross-section of the sample.



(a) (b)

Figure 1. Morphology of transverse and longitudinal sections of ingot specimens before corrosion.

The microstructure of the transverse and longitudinal sections of the ingot specimen after corrosion is shown in figures 2 (a) and (b). It can be seen that the grain size is relatively uniform and the grain boundary is excessively round, which is an obvious as-cast structure.



(a) (b)

Figure 2. Microstructure of the ingot specimen after corrosion in transverse and longitudinal sections.

Energy spectrum analysis was carried out on the inclusions in Inconel600 nickel-chromium iron ingot sample. As can be seen from figure 3, the inclusions are spinel oxide Mg0·Al2O3, ridged TiN, and oxide type inclusions CaO and MgO. The inclusions are very small, all about 2um.

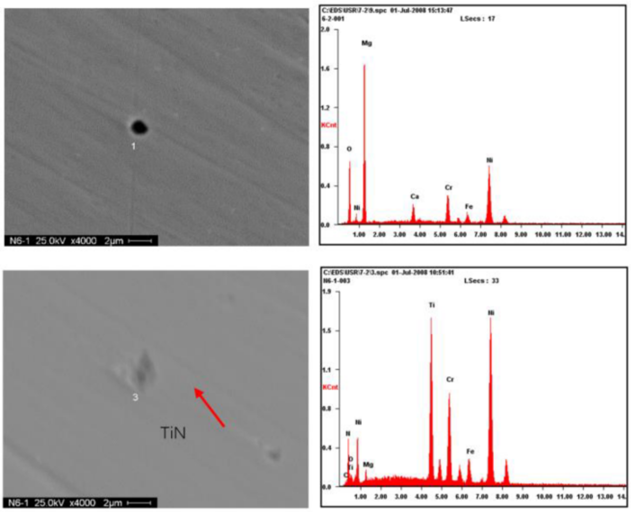


Figure 3. Morphology of ingot specimens before corrosion.

3.3. Quality of Finished Silk Material

The surface of hot rolled disk element is smooth, good quality, no "ear", folding, scar, crack and other defects, the size deviation is in line with gb_T_15008-1994 corrosion resistant alloy bar standard provisions. Samples were taken from Inconel600 nickel-ferrochrome alloy disks for microstructure analysis. As can be seen from figure 4, the surface of hot rolled Inconel600 nickel-ferrochrome alloy coil is clean and grain size is evenly distributed.

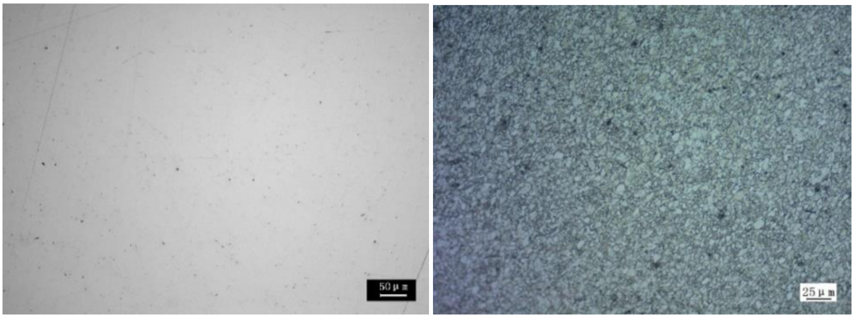


Figure 4. Microstructure of Inconel hot rolled disk element.

3.4. Tensile Properties of Products

Three samples were taken from the head, middle and tail parts of the finished wire, and the mechanical properties were tested by electronic universal material testing machine. Mechanical property parameters are shown in table 4. With the increase of strain, the stress value increases, Inconel600 nickel-ferrochrome alloy in the plastic deformation process constantly hardening, so must rely on the continuous increase of applied stress, plastic deformation can continue. When the strain reaches a certain value, the stress does not increase, the alloy continues to harden, the strain increases, the stress increases gently, and enters the stable strain stage until fracture. The results show that the Inconel600 nickel-ferrochrome alloy has good plasticity and strength, and the tensile strength meets the national standard.

Table 4. Mechanical properties of Inconel600 alloy at room temperature.

	$Rp_{0.2}$	E-Modulus	Rm	Ag	A
1	N/mm^2	kN/mm^2	N/mm^2	%	%
2	218.75	172.0	1341.01	23.85	26.24
2	219.50	161.9	1338.01	22.35	24.01
3	221.39	170.3	1339.77	21.74	23.93
4	218.77	128.9	1335.31	24.34	26.50
5	218.59	146.7	1335.89	24.34	26.90
6	216.68	117.9	1335.48	25.71	27.72
7	242.27	191.8	1354.72	17.24	19.29
8	242.84	214.9	1351.93	15.40	16.37
9	238.95	188.7	1350.29	18.47	20.55

The tensile fracture morphology was analyzed by scanning electron microscope. Figure 5 shows the scanning graph of fracture. As can be seen from the figure, the fracture is ductile fracture. The metal particles during fracture are distributed in the matrix of the alloy. Fracture of ductile fracture generally find fiber area and shear lip area, fracture scale is larger also radiate and herringbone ridge shape pattern, fiber area is commonly fracture source area, shear lip is always at the edge of the fracture, and about 45 ° Angle and the surface of the components, shear force under the condition of plane stress occur is the tear of fracture, shear lip surface more smooth. The three zones of ductile fracture are not obvious due to the selection of microzones.

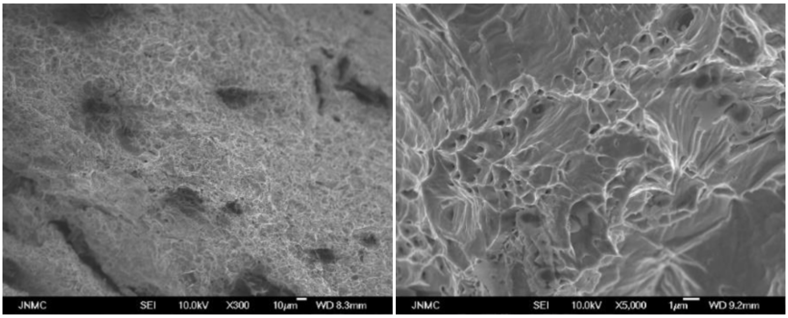


Figure 5. Scanning spectrum of finished wire fracture.

4. Conclusion

It is feasible to melt Inconel600 nickel-ferrochrome alloy with non-vacuum intermediate frequency. In this experiment, Inconel600 nickel-ferrochrome alloy products were successfully trial-produced by adding 0.1% titanium metal with mass fraction, smelting in strict accordance with the established scheme, and hot processing after forging and rolling process. The chemical composition of Inconel600 nickel-ferrochrome alloy products is qualified, the hot working parameters are reasonable, and the finished surface quality obtained by drawing process is good. The strength and plasticity meet the requirements of national standards. The metallographic structure is uniform, compact and without porosity.

References

[1] Chen KZ, Xia JB. Study on trial production of GH600 alloy. Special Steel Technology. 2004 Mar; 10(1): 3-6.
[2] Yang X, Su XW. Study on the properties and application of domestic Inconel alloy tube. Nuclear Power Engineering. 1997 Jun; 18(3):169-173.
[3] Ma LG, Ding WZ, Li L. Deoxidation and desulfurization of Inconel600 in smelting. Transactions of Materials and Metallurgy. 2011 Oct; 10(z1):61-63.
[4] Wang Ch, Dong SM, Zhang HY. Analysis of microstructure and properties of Inconel600 alloy wire. China Building Materials Science and Technology. 2015 Feb; 24(1):60-62.
[5] Wang YH. Study on trace elements and inclusion morphology of Inconel600 and 4J43 alloys. Gansu: Lanzhou University of Technology. 2015.
[6] Liu TZ, Liu N, Shen J, Wang XJ, Xia TD. Advances in research on influential factors of longevity for Cr20Ni80 electric-resistance alloy. Nonferrous Metals. 2010 Aug; 62 (4): 34–37.
[7] Fan Y, Zhou X, Cao J, Cao Y, Chen JC. Usability of Cr20Ni80 alloy and influence factors. Hot Working Technology. 2013 Oct; 42(20):42–46.
[8] Kubisztal J, Budniok A, Lasia A. Study of the hydrogen evolution reaction on nickel-based composite coatings containing molybdenum powder. International Journal of Hydrogen Energy. 2007 Sep; 32 (9): 1211–1218.
[9] Dudova NR, Kaibyshev RO, Valitov VA. Deformation mechanisms in Cr20Ni80 alloy at elevated temperatures. The Physics of Metals and Metallography. 2009 Apr; 107 (4):409–418.
[10] Namkung J, Kim MC, Park CG. Effect of Si addition on the magnetic properties of melt-quenched Ni–Fe alloy strip. Materials Science and Engineering A. 2007Mar; 449-451(1):430-434.