Ti-2007 Science and Technology, edited by M. Ninomi, S. Akiyama, M. Ikeda, M. Hagiwara, K. Maruyama The Japan Institute of Metals (2007)

Experience in Using Scull Arc Remelt for Production of Multi-Component Titanium Alloys

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Method of scull and subsequent vacuum remelting of titanium alloy ingots (Scull+VAR) was traditionally used at VSMPO for manufacture of Russian alloy ingots. Certification of this manufacturing method by leading aircraft building companies allowed to expand the mix of melted alloys. Quality of ingots and billets produced by Scull+VAR and VAR+VAR methods was compared by the example of a highly sensitive to segregation alloy 10V-2Fe-3Al.

Key words: melting, scull, inclusions, refining effect, homogeneity, mechanical properties.

1. Operation Principle of Scull Arc Furnace

Scull arc furnace is a melting unit, where metal is melted and accumulated in liquid condition on the scull hard layer of remelted metal, built up on the bottom and walls of a copper water-cooled melting pot, and, upon completion of melting, poured into the mould or crucible. To melt the metal an electric arc is used with a consumable electrode. Fig. 1 shows a scheme of a scull arc furnace. Fig. 2 shows photograph of a scull arc furnace appearance.

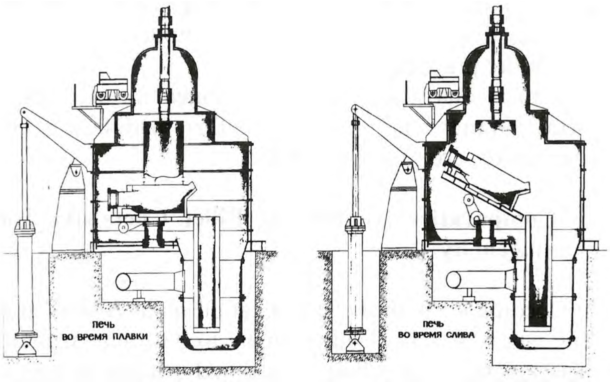


Figure 1. Scheme of a Scull Arc Furnace

Figure 2. Appearance of a scull arc furnace

Scull from the previous melt is used as a consumable electrode, thus the process is called scull — consumable electrode process (Scull). When melting according to the scull process charge materials — initial charge and reverts - are loaded into a copper water-cooled melting pot in any ratio, the furnace is pumped down, electric arc is ignited and melting is carried out using the previous melt scull as a consumable electrode. Then the metal is poured into the mould, cooled to the required temperature, the furnace is depressurized, the scull is removed from the melting pot and the ingot - from the crucible. Then the cycle is repeated. Thus, when melting according to the scull remelt process it is not required to prepare consumable electrodes, except for the initial melt.

The major advantages of a scull melt as compared to both vacuum-arc melting in a crucible and cold-hearth melting (plasma-arc or electron beam) are as follows:

- homogeneity of ingot chemistry owing to all ingot metal being in liquid condition at the moment of pouring,
- possibility of introducing bulky scrap,
- reliable removal of particles with density and melting temperature higher than the matrix metal from the melt. These particles are precipitated during the melt in the scull and do not get into the ingot. Gas saturated particles with density close to the alloy density are dissolved due to longer time of interaction with molten metal.

Refining effect of the Scull remelt method was confirmed by research work on ingot melting with defect seeding. In the course of research work two ingots were manufactured, one of which was manufactured by triple VAR, the second — by Scull+VAR method. Gas saturated and high density particles were introduced into the charge material of each of the ingots. List of

Table 1. Types of Defective Solids, Introduced into Melts

Type of Defective Solids	Size, mm	Number per 1 ingot
Nitrogenized sponge with nitrogen content of:		
6%	5 – 15	100
12%	5 – 15	100
15.7%	5 – 15	100
Burnt sponge	5 - 15	50
Hard-alloy solders of cutters	10 - 20	10
Solids with evidence of flame cutting	50 - 100	10

Evaluation of defect presence was carried out by ultrasonic inspection of 30 mm diameter bars, manufactured from the evaluated ingots.
Result correlation of refining ability evaluation of a triple vacuum-arc remelt and a Scull+VAR method is demonstrated in Fig. 3.

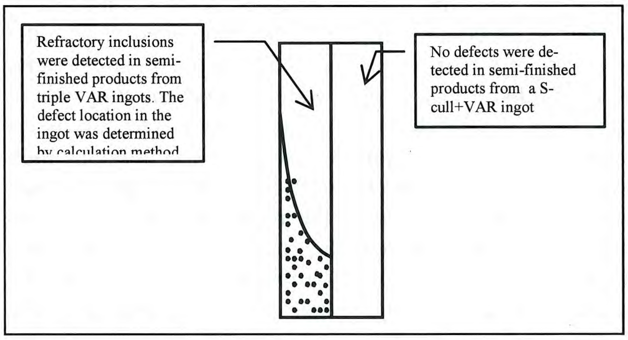


Figure 3. Defect presence in 030 mm bars, manufactured from a triple VAR ingot (left half of the drawing) and a Scull+VAR ingot (right half of the drawing), melted with seeding of defective solids

Shape and overall dimensions of charge materials used in scull furnaces are limited only by the dimensions of the crucible useful area. Solids are used almost without crashing, what significantly reduces labor content of their preparation and metal loss at this operation. Besides the scull arc melting method allows to produce defect-free ingots even when using scrap with laps, funnels, alpha-layer, which was not removed. Recent experience in melting of Ti-6A1-4V alloy ingots for bar manufacture with the diameter of less than 60 mm and ultrasonic inspection results of semi-finished products confirm this statement.

Owing to the above mentioned advantages the scull melting is currently a perspective manufacturing process of aircraft and rotor quality ingots.

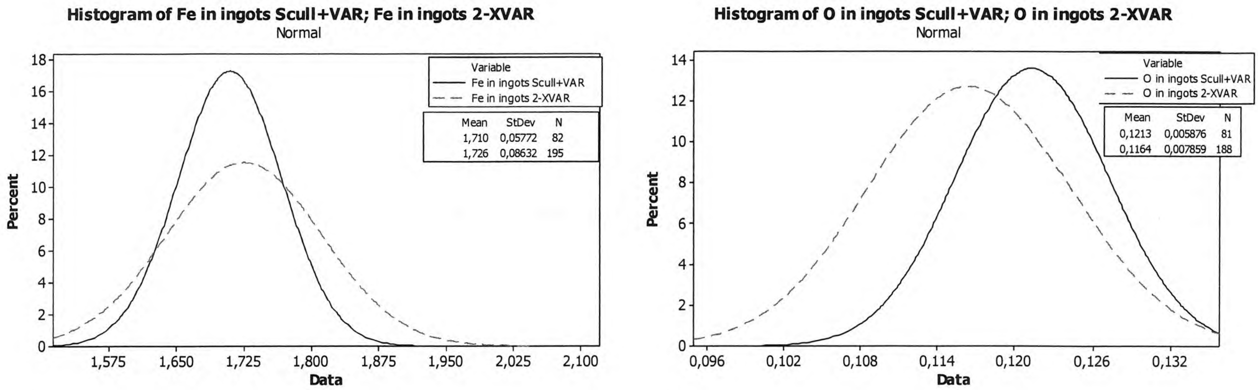
2. Comparative Analysis of Ingot Chemistry Homogeneity

Melting of quality and chemistry homogeneous ingots of 10-2-3 alloy is associated with a number of difficulties, caused by high iron content in the alloy and segregation processes related to it. Segregation processes may be suppressed by melting ingots at low currents with a shallow molten pool.
A method of 10-2-3 alloy ingot melting using scull remelt and subsequent vacuum-arc remelt was successfully implemented at VSMPO-AVISMA Corporation in batch production. Processing of statistical data on alloying component content of ingots and billets manufactured from them showed that ingots melted by a Scull+VAR method have higher homogeneity in iron and oxygen, i.e. elements which are the most critical with regard to segregation and namely β-fleck occurrence, as compared to double VAR ingots. To illustrate this conclusion Fig. 4-5 show normal distribution curves of iron, oxygen, vanadium and aluminum content in 41 ingots of 10-2-3 alloy manufactured by a Scull+VAR method and in 95 ingots, manufactured by a double VAR. Comparative analysis of the curves also shows that, with respect to aluminum and vanadium distribution, the ingots manufactured by two methods are practically identical.
Summary statistical data on homogeneity of element distribution in the ingots of 10-2-3 alloy, manufactured by two methods, are shown in Table 2.

3. Comparative Analysis of Billet Chemistry Homogeneity

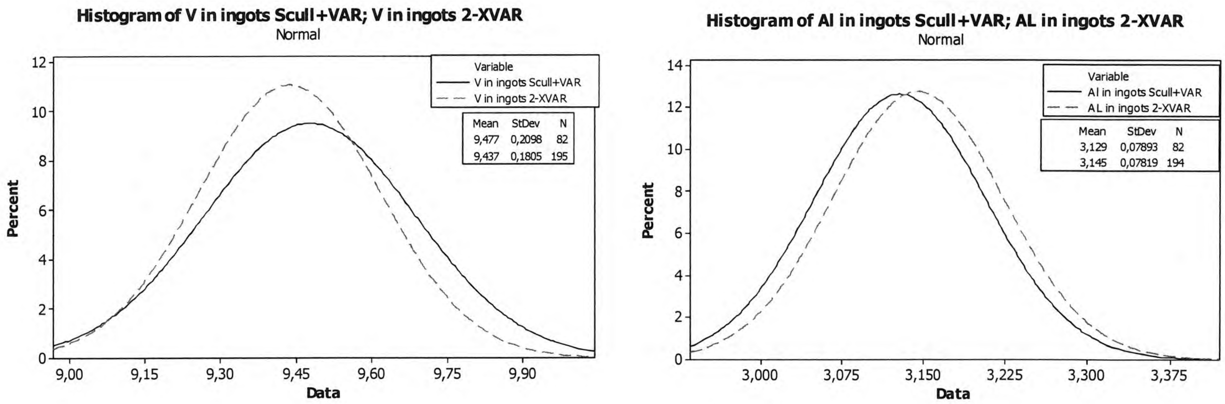
In accordance with the specification requirements after deformation of 10-2-3 alloy ingots to 330 mm diameter billets repeated inspection of iron and oxygen content is carried out through the section of each billet. Results of billet chemistry inspection are shown as normal distribution curves in Fig. 6.
Summary statistical data on homogeneity of element distribution in billets from 10-2-3 alloy ingots, manufactured by two method, are shown in Table 3.
Based on the dispersions (standard deviations) of element distribution in ingots and billets the following may be concluded.

1) Use of the scull melting method as a first remelt for 10-203 alloy ingots increases ingot homogeneity in oxygen and iron — the most critical elements with regard to β-fleck formation. In this case an absolute value of iron content for ingots, melted by two methods, is the same. Absolute value of oxygen content in Scull+VAR ingots is a bit higher than in double VAR ingots.
2) Method of ingot melting as per the Scull+VAR scheme has practically no effect on aluminum and vanadium distribution as compared to double VAR.



a) b)

Figure 4. Distribution curves of a) iron and b) oxygen in 10-2-3 alloy ingots

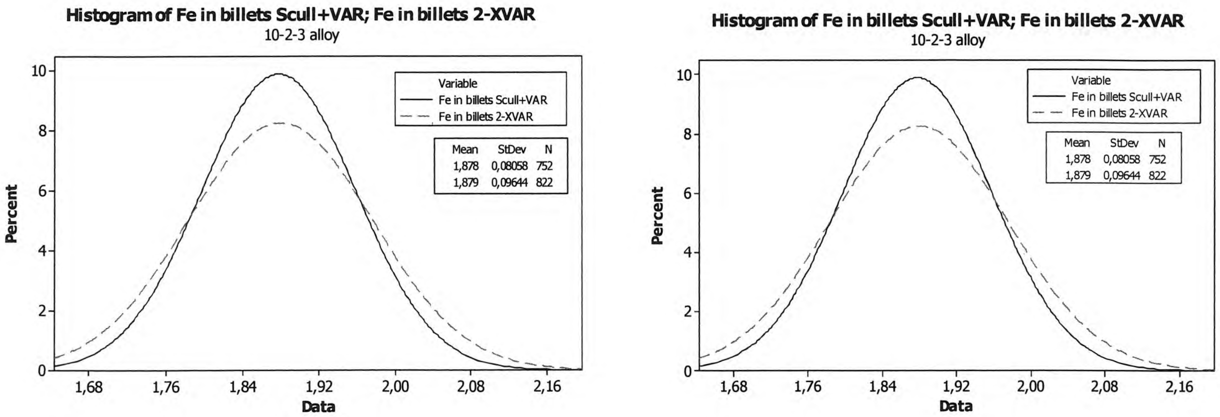


a) b)

Figure 5. Distribution curves of a) vanadium and b) aluminum in 10-2-3 alloy ingots

Table 2. Statistical Data on Element Distribution in 10-2-3 Alloy Ingots, Manufactured by Scull+VAR and double VAR Methods

	Oxygen		Iron		Aluminum		Vanadium	
Statistical Characteristic	Scull+ VAR	2VAR	Scull+ VAR	2VAR	Scull+ VAR	2VAR	Scull+ VAR	2VAR
Minimum Value	0.09	0.087	1.6	1.6	2.93	2.97	8.66	9.08
Maximum Value	0.13	0.13	2.04	2.1	3.4	3.4	10.3	9.98
Standard Deviation	**0.0059**	**0.0079**	**0.0578**	**0.0863**	**0.0789**	**0.0782**	**0.2098**	**0.1805**



a) b)

Figure 6. Distribution Curves of a) Oxygen and b) Iron in Billets of 10-2-3 Alloy

Table 3. Statistical Data on Element Distribution in Billets of 10-2-3 Alloy Manufactured by Scull+VAR and Double VAR Methods

Statistical Characteristic	Oxygen		Iron	
	Scull+ VAR	2VAR	Scull+ VAR	2VAR
Minimum Value	0.094	0.081	1.70	1.67
Maximum Value	0.130	0.130	2.12	2.24
Standard Deviation	**0.0079**	**0.0100**	**0.0806**	**0.0972**

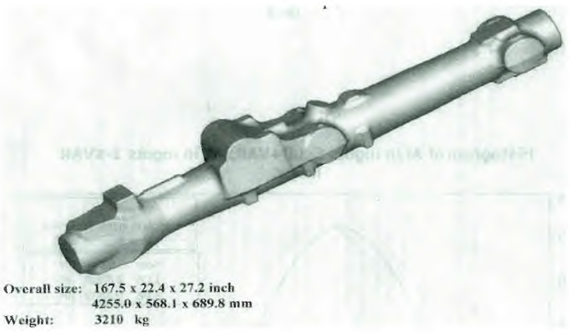


Figure 7. Sketch of 3III577 Die Forging

4. Comparative Analysis of Mechanical Properties

Comparison of mechanical properties was carried out for die forgings with the same configuration, manufactured as per one process, initial materials for which were Scull+VAR and 2VAR ingots. A die forging sketch is shown in Figure 7.

2 specimens were taken from the material of each die forging for room temperature tensile tests. Statistics on mechanical properties was analyzed using the material of 11 die forgings, manufactured by double VAR, and 8 die forgings, manufactured by a Scull+VAR method. Normal distribution curves of mechanical property values are shown in Fig. 8-10.

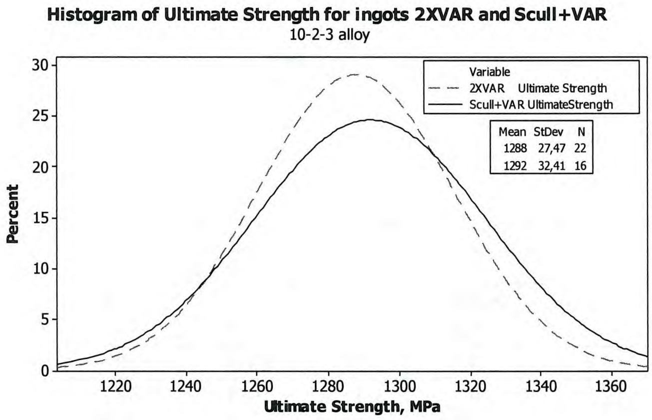


Figure 8. Normal Distribution Curve of Ultimate Strength Values of 577 Die Forgings

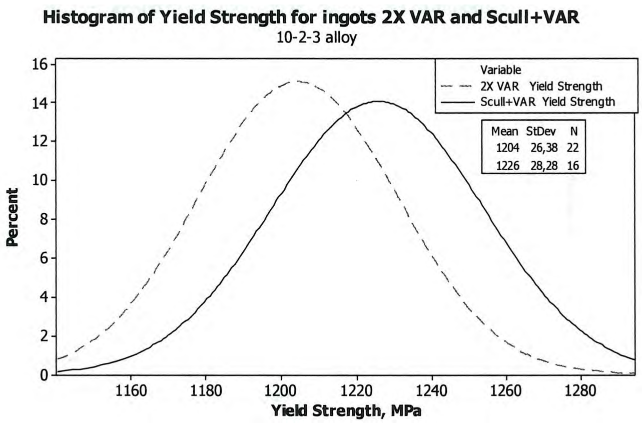


Figure 9. Normal Distribution Curves of Yield Strength Values of 577 Die Forgings

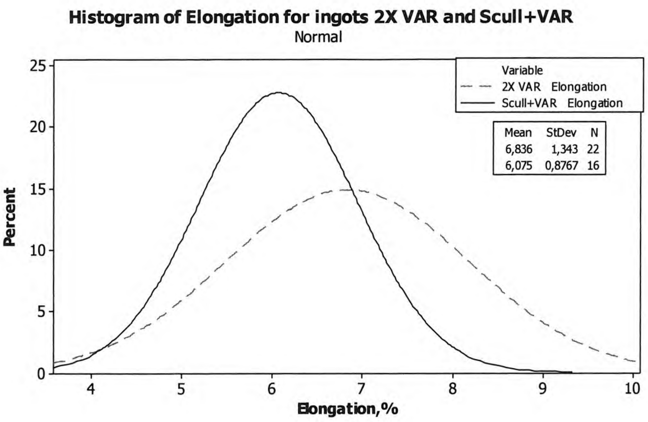


Figure 10. Normal Distribution Curves of Elongation Values of 577 Die Forging Material

Table 4. Statistical Data on Element Distribution in 10-2-3 Alloy Ingots Manufactured by Scull+VAR and Double VAR Methods

Statistical Characteristic	Ultimate Strength, MPa		Yield Strength, MPa		Elongation, %	
	Scull+ VAR	2VAR	Scull+ VAR	2VAR	Scull+ VAR	2VAR
Minimum Value	1215.0	1234.2	1148.0	1146.4	5.0	5.1
Maximum Value	1336.9	1336.0	1262.0	1250.0	7.9	9.4
Standard Deviation	**32.41**	**27.47**	**28.28**	**26.38**	**0.88**	**1.34**

Statistical data on mechanical properties of 10-2-3 alloy die forgings, manufactured from the Scull+VAR and 2VAR ingots, are given in Table 4.

As it is seen, strength properties of die forgings, manufactured from the Scull+VAR ingots, are at the same level with strength properties of die forgings, manufactured from the double VAR ingots. As to ductility properties, die forgings from the Scull+VAR ingots are more homogeneous, than die forgings from the 2VAR ingots.

5. Summary

1) Melting method of 10-2-3 alloy ingots using scull furnaces at the first remelt was adjusted and implemented into batch production. Melt in a scull

2) Comparative analysis of chemical homogeneity and mechanical properties was carried out for 10-2-3 alloy ingots, melted as per the Scull+VAR method and ingots, melted by double VAR.

3) Homogeneity of ingots, melted by the Scull+VAR method as compared to the ingots manufactured by a traditional double VAR process is higher with regard to the most critical elements — oxygen and iron.

4) It was shown that mechanical properties of material of die forgings manufactured from ingots of different melting processes are approximately at the same level. Some strength increase and ductility reduction of die forgings from the Scull+VAR ingots as compared to the die forgings from the double VAR ingots is explained by higher oxygen level.