Comparative study of melting stock for investment casting

Several types of melting stock material exist today. Some casters purchase scrap and raw materials and try to reach an optimal chemical analysis on their own. Others buy bars, ingots or GRANSHOT™, Uddeholm Technology's granulated melting stock. Kristina Beskow and Ulrika Svensson Pokrzywka* Uddeholm Technology AB, Sweden, describe a study of the relative merits of the different melt stock materials.

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A good knowledge of the properties of the raw material used will help to optimise the casting process and can also have an impact on the final quality of the product. It is also important from an energy and cost saving perspective. Important parameters to consider in the choice of a raw material are for example melting times, charge times and convenience, material yield, constant/high quality, chemical analysis stability and material purity. In this experimental study the Uddeholm Technology GRANSHOT material has been compared to other melting stock alternatives; ingots and premix material, for two different steel grades, the low alloyed 2244 (similar to W. nr. 1.7225 and ASTM A 732) and the stainless steel grade AISI 316L.

Experimental conditions

GRANSHOT was melted and compared to alternative melting stock material in the form of ingots and premix material. Two standard steel grades, low alloyed 2244 and high alloyed AISI 316 L, were investigated. The parameters studied during the experiments were melting time, handling properties of material during meltdown and chemical analysis accuracy. Measurements were also made to evaluate the liquidus temperature for each steel grade. The study of the melting times was only made for steel grade 2244 while the other parameters were investigated for both steel grades.

Material preparation - A material weight of 100kg was prepared for each experiment. The furnace was filled to approximately two thirds with material and was filled continuously until all 100kg had been added. Two to three heats were made for each material type. The premix material used during the experiments was prepared from standard raw material and alloys from normal suppliers. During the preparation procedure extra care was given to the accuracy in weighing raw materials to meet the target composition. The ingots used were in sizes of approximately 7kg. The GRANSHOT granules have a bulk density of about 4kg/l and an average size range of 8 to 15mm.

Experimental procedure - Material was melted in a 100kg high frequency Inductotherm 225kW Vip furnace, which is similar to the type of furnace used in many investment casting foundries. During meltdown of material the furnace settings were adjusted to obtain optimum melting conditions. The furnace power was kept as constant as possible in between each experiment and in between different melting stock materials. The energy consumption was not measured during the experiments.

The time taken for all material to melt was determined for each heat, and a temperature measurement was taken just after complete melting. The melting time was defined as the total time from start of the furnace until all material (100kg) was completely melted. The time for complete melting was determined by ocular examination of the metal bath in combination with stirring of the bath with a metal rod. Steel samples for chemical analysis were taken after complete melting and before tapping. Adjustment of the chemical composition was not made during the experiments.

For each heat a sample was cast into a thermal analysis cup to measure the temperature during solidification. The solidification curve was used to evaluate the liquidus temperature.

Results and discussion

Melting times – In total six experiments to measure the melting times were carried out for steel grade 2244. The results are presented in table 1. In the table the times have been normalised to correspond to the same metal bath temperature after meltdown (1502°C), to give a more correct comparison. For heats B and F a correction was also made to the melting times to take into account the difference in melt weight. The normalised times are presented in a separate column in table 1.

As can be seen from the results the melting times for the GRANSHOT material was considerably shorter compared to those of ingots and premix material. In the case of premix the GRANSHOT melts were almost 50 percent faster, while compared to ingots the melting time was approximately 30 percent shorter. By keeping a rest melt from previous heat in the furnace (Heat B, 8kg rest melt) the melting time could be further decreased.

Material handling properties - During the experiments the handling properties of the different melting stock materials were compared. A great advantage using the GRANSHOT granules is the possibility to obtain very exact amounts, which makes them convenient to use, especially in smaller sized furnaces often used by investment casters. The size distribution also makes them easy to handle compared to ingots that are heavier and more ungainly to use. Depending on furnace size, cutting of ingots might be necessary to obtain the right amount of material. This will add an extra step in the production process for the caster. Addition of GRANSHOT into the furnace is illustrated in fig 1.

For the premix melts, especially for the low alloyed 2244, a large amount of pure iron in the form of small scrap pieces was charged. The large volume of scrap

Material type	Heat no.	Melt weight [kg]	Melting time [min] (normalized with respect to temperature)	Melting time [min] (normalized with respect to melt weight)
GRANSHOT™	A	100	16	–
	B	92 + 8 kg rest melt	14.5	15.5
Premix material	C	100	29	–
	D	100	29	–
Ingot	E	100	23	–
	F	89	22	24.5

Table 1. Obtained melting times for steel grade 2244.

made the addition time consuming and required more work from the furnace operator, which also affected the total process time. The handling of premix material is therefore dependent on the type and size of raw material used and on the steel grade produced.

Chemical analysis accuracy - To investigate the analysis accuracy of the different materials, steel samples were taken after complete meltdown and before casting. The samples were thereafter analysed for chemical composition. The results showed that the GRANSHOT and ingot heats were well within the analysis boundaries for both grade 2244 and 316L. A comparison of chemical analysis of the charged GRANSHOT raw material with the analysis of the steel samples taken during melt down showed no significant composition differences. The larger surface area of the GRANSHOT product was not found to increase the risk of oxidizing during melt down, for either the low alloyed or high alloyed steel grades.

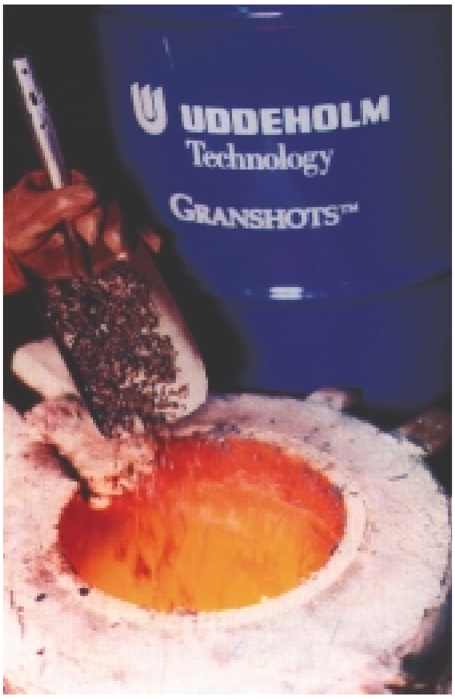

Fig 2. Charging GRANSHOT into a furnace

For the premix material none of the heats had fulfilled the chemical analysis specification completely. The main deviation for steel grade 316L was for elements C and Cr, and for grade 2244 for C, Cr Si and Mn. This means that even though special consideration was given to accuracy in weighing of raw materials during preparation of the premix heats, none of the heats met the target composition without extra analysis adjustments being necessary. Using premix as a raw material therefore requires thorough analysis control and possible adjustments in order to meet the target composition. This means extra work for the investment caster as well as increased process time, analysis costs and power consumption.

Liquidus temperature measurements - During casting knowledge of the liquidus temperature is essential for the interpretation and modelling of the solidification behaviour of an alloy. Controlling the solidification is the key to the outcome of the final quality of the cast product. In the current investigation, temperature measurements during solidification were carried out for each steel grade and material type to evaluate the liquidus temperature (TL). The evaluated liquidus temperatures are presented in table 2. Because of the discrepancy in final composition for the premix heats the liquidus temperatures for the premix material are not included in the results.

		Calculated T_L			
Material	**Measured T_L**	**Formula 1**	**Formula 2**	**Formula 3**	**Formula 4**
Steel grade 2244					
GRANSHOT™	1480	1487	1490	1489	1493
GRANSHOT™	1479	1488	1489	1489	1493
Ingot	1479	1474	1477	1477	1482
Steel grade 316L					
GRANSHOT™	1430	1441	1455	1437	1418
GRANSHOT™	1431	1440	1454	1437	1417
GRANSHOT™	1430	1441	1454	1437	1418
Ingot	1431	1445	1455	1440	1424

Formula 1: TL = 1536-75.81*%C-11.84*%Si-19.13*%Mn-%Cr-2.95*%Ni-3*%Mo
Formula 2: TL = 1534-91*%C-7.6*%Si-4.9*%Mn-34.4*%P-38*%S-1.3*%Cr-3.1*%Ni-4.7*%Cu-3.6*%Al
Formula 3: TL = 1536-100.3*%C+22.4*(%C)^2-0.61-13.55*%Si+0.64*(%Si)^2-5.82*%Mn+0.3*(%Mn)^2-1.59*%Cr+0.007*(%Cr)^2-4.18*%Ni+0.01*(%Ni)^2-4.2*%Cu
Formula 4: TL = 1536-83.9*%C+10*(%C)^2-12.6*%Si-5.4*%Mn-1.5*%Cr-5.1*%Ni-3.3*%Mo-30*%P-37*%S-9.5*%Nb

Table 2. Measured and calculated liquidus temperatures for steel grade 2244 and 316L.

For comparison an attempt to calculate the liquidus temperatures from the analysed steel compositions was made by using empirical expressions commonly used in the industry. Four different formulas were compared. The calculated results are also included in table 2.

The measured values show a very good consistency within each steel grade respectively. Based on the good agreement in measured values, the liquidus temperatures for both steel grades can be said to have been measured accurately in the present investigation.

Comparisons made using the calculated values show that the liquidus temperatures vary considerably, depending on the formula used. The largest deviations are seen for steel grade 316L, while for 2244 the calculated values are closer to the measured value because of the lower alloying content of the material. The slight composition difference in between heats of the same steel grade seem to have a larger influence on the calculated values than the real measured values. Table 3 shows the calculated liquidus temperatures based on the minimum and maximum values of the given standard composition range for each steel grade.

Even though the calculated values are not exact they give a good indication of the impact that a wide composition range will have on the liquidus temperature. The importance for the caster to have a reliable value is essential to the outcome of the cast product. This further emphasises the advantage of using a raw material with high analysis accuracy every time, to minimise the risk of variations in liquidus temperature. The results also show the importance for casters to demand narrow composition ranges from the melting stock suppliers to ensure a good quality during casting, especially for high alloy material.

Summary

GRANSHOT was compared to alternative melting stock material supplied in the form of ingots and premixed material (mix of pure iron and alloys) used for investment casting purposes. Melting experiments were carried out in a 100kg high frequency furnace for two standard steel grades. Investigated parameters were melting times, material handling properties, chemical analysis accuracy and liquidus temperature.

The melting tests for steel grade 2244 showed that the GRANSHOT material melted considerably faster compared to ingots and premix material. Another great advantage when using the GRANSHOT granules was found to be the possibility to obtain very exact charges. These can be within a few grams of deviation when charging a furnace. Size distribution of the GRANSHOT material also made them convenient to handle.

When it comes to analysis accuracy both GRANSHOT and ingot heats were well within the analysis boundaries for both steel grades, while none of the premixed heats fulfilled the chemical analysis specification completely. Using a premixed raw material therefore requires thorough analysis control and possible adjustments in order to meet the target composition. This means extra work for the investment caster as well as increased process time, analysis costs and power consumption.

The results from the liquidus temperatures measurements showed the advantage of using a raw material with high analysis accuracy in order for the caster to have a reliable value of the liquidus temperature. The results also showed the importance for casters to demand narrow composition ranges from melt stock suppliers, to ensure good quality during casting, especially for high alloy material.

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Calculated T_L	**Steel grade**			
	316 L		2244	
	Min comp.	Max comp.	Min comp.	Max comp.
Formula 1	1483	1415	1488	1475
Formula 2	1481	1444	1492	1479
Formula 3	1470	1426	1490	1477
Formula 4	1454	1399	1495	1482

Table 3.