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Ferroboron Melting Control in Thermite Mixture

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***Abstract* — Local or partial metal flow alloying allows make castings with differential properties. For alloying cast iron with super high temperature ferroalloys, including iron boron, uses thermite. This allows treat cast iron in casting mold. To control the melting process is proposed to use the integral parameter characterizing the flow of a thermite reaction depending on the amount of thermite and ferroboron. The value of the integral parameter to be determine whether will be complete ferroboron melting and how fast it dissolution will happen. Found that complete ferroboron melting is at the integral parameter value within interval 2,33-4. Accordingly, changes speed melting and ferroboron amount that will fall in cast iron. The dependence between the value of the integral parameter and speed flow of thermite reaction was established. The mathematical models that describe the change of integral parameters value depending on the ratio of termites and ferroboron and ferroboron faction were developed. Controlling integral parameter value allows adjust the amount of alloy element in cast iron.**

Keywords— Burning Time, Double-Layer Casting Part; Heat Flow Path, Iron Aluminum Thermite Burning Kinetics; Ferroboron Melting Kinetics Integral Parameter.

I INTRODUCTION

1.1. Thermite mixture in casting production

When making castings thermite mixture, commonly, are used for heating the risers. This allows reduce riser volume up to 50 % without compromising casting feed [1].

At the same time, thermite riser shells actively used for thermite metal alloying. These shells usually contain 22 % aluminium powder, 52 % scaling, 2 % fluorite, 19 % milled chamotte, 5 % bentonite clay, ferroalloys and others materials [2]. Ferroalloys and additional materials used to achieve thermite metal the composition of casting melt.

To increase the efficiency of thermal riser shells the mixture are compacted to 680 – 3400 kg/m^3 [3]. This compaction enables further reduce the riser volume.

Consequently, the main use is exothermic risers reduce their volume without reducing the metal casting feeding.

Last but not least advantage of the metallthermic process is the use waste of heat treatment, foundry and metal processing (iron scale, powder of aluminum shavings, screening ligatures, dust from the air filters at foundry shops, powder of non-fired parts of graphite electrodes and others).

Much attention in the study was paid for design, the compacted degree of thermite risers and content of additional components, providing the necessary temperature and chemical composition of the melt, mainly steel. In addition, it is believed that alloying components are in thermite evenly. This factor is not essential when using risers because the combustion process in termites risers continue during 30 seconds, and the crystallization of castings can take up to 5 minutes. This time is enough to align thermite metal chemical composition.

Browse recipes for thermite mixture for risers showed that the total content of alloying component does not exceed 5% by weight of thermite [4, 5, 6]. This is sufficient for alloying thermite metal in riser, but not enough for alloying the melt flow.

At the manufacture of double-layer casting or differential alloying metal casting parts it is necessary to have a sufficient amount of alloying elements. This is achieved by using alloying elements (ferroalloys) inserts in bulk (no compacted) thermite [7].

The linear burning rate not compacted termites is a constant value and depends only on the amount of alloy [8].

Changing the quantity of alloying alloy can influence the speed of the thermite reaction and the amount of alloying elements entering the melt.

1.2. Thermite mixture

Aluminothermic reactions are widely used for a large number of clean carbon-free metals: chromium, manganese and others. The process takes place in the next reaction

$$3Fe_3O_4+8Al=9Fe+4Al_2O_3+774\ \text{kCal}$$

The characteristic features that distinguish thermite burning process from other pyrotechnic mixtures are:

- Absence gaseous reaction products during combustion;
- High temperature combustion reaction, for most thermites it is 2000…2800 °C;
- Formation the liquid molten slag during combustion.

Regular composition iron aluminum thermites: 22-25 % aluminum and 75 -78 % iron scale.

1.3. Boron

Ferroboron microalloying up to 0.05% reduces cast iron chilling, but further it content increasing leads to increased chilling [12,13]. At a concentration of 0.20...0.25% boron chills cast iron, forms boron fusible eutectic, is a part of cementite in the form of mixed compounds of variable composition $Fe_3(C,B)$ and forms transcrystalline cast iron chill in the samples with diameter up to 150 mm.

At boron content in cast iron more than 0.08% the number of carbides increases rapidly (mainly by reducing the perlite). Generally, boron concentrated in carbide and graphite, and in metal-based it content not exceeding 0.006...0.008 %. Boron creates solid solution with γ-iron, and with α-iron – solutions of penetration and replacement [14,15].

Boron is one of the few elements, which small additive dramatically changes the stability of the graphite complexes, weakening bonds in the ring flat hexagonal graphite molecules with subsequent transfer of carbon in the true liquid solution and creates iron, manganese and boron carbides during cast iron crystallization.

So adjusting the boron content in iron casting and cooling rate can obtain cast iron with different structures and properties, which is important in double-layer castings production.

1.5. Dissolution of ferroalloys

Ferroboron is high-melting ferroalloys with melting point above the cast iron pour temperature. Its melting is impossible without formation of low-melting compounds. During the 1st period high-melting ferroalloy is under solid cast iron crust, which prevents its direct contact with the melt. The length of this period is determined with heat exchange between the ferroalloy piece and melt. During the 2nd period, solid ferroalloy is dissolves without melting. At this time, formation of low-melting compounds is possible. Duration of this period is determined, mainly, with mass transfer. Thermal effects can increase or decrease ferroalloy dissolution time [17].

1.6 Conclusion

- The use of thermite mixture in heating risers is effective to reduce the riser size and quality feeding casting, but very limited for alloying the melt.
- The amount of thermites layer heat depends on reaction area, i.e. the diameter of thermite.
- Using alloys inserts with different diameters can adjust the thermite reaction speed and amount of alloying elements in the melt.

The aim of the work is to determine the parameters that characterize the passage thermite reaction using ferroboron inserts.

To do this, the influence of the ratio of cross-sectional area of the ferroboron insertion and the cross-sectional area of thermite on the thermite burning time and completeness melt ferroboron.

2 MATERIALS AND METHODS

2.1 Mold

For the ferroboron melting kinetics among iron aluminum thermites study was used a dried open mold with a cylindrical hole d=50 mm, h=50 mm from sand-clay mixture, which composition is given in Table 2.1.

TABLE 2.1 – MOLD MIXTURE COMPOSITION

Component	Content, %
Recycling mixture	95…98
Sand	2…4
Clay	0,25
Water	2…3

The cylindrical ferroboron insertion with 50 mm height was place into the middle of mold hole. Brand of ferroboron is FB20 (GOST 14848-69). The chemical composition is shown in Table 2.2.

TABLE 2.2 – CHEMICAL COMPOSITION OF FEB20.

Element	B	C	Si	S	P
Content, %	≥20	≤0,05	≤2	≤0,01	≤0,015

Remaining space was filled with iron aluminum thermite (Fig. 2.1). Ferroboron insertions diameters were 10, 15 and 20 mm. Ferroboron particles size were ≤1 mm; 1...2.5 mm; 2.5...5 mm.

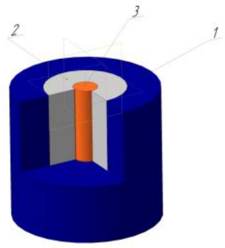

Fig. 2.1 Sand mold for investigation. 1 – sand mold; 2 – iron aluminum thermite; 3 – ferroborron insertion.

2.2 Experiment planning

Independent variables levels were selected:

X1 – 1; 1.5; 2 cm – ferroboron insertion diameter;

X2 – 1; 2.5; 5 mm – ferroboron fractional composition;

As a response were used iron aluminum thermites burning time and ferroboron molten quantities.

3 EXPERIMENT

3.1 The influence of geometrical parameters of ferroboron melting

For determine the effect of geometrical parameters for ferroboron melting the next values were calculated: perimeter, area, volume, bulk density and ferroboron interaction area for inserts of different diameters and size distribution. The data presented in Table 3.1.

TABLE 3.1 GEOMETRIC FERROBORON INSERTS

	The insertion diameter, cm			
	1	*1,5*	*2*	*1+1**
Perimeter, cm	3,14	4,71	6,28	6,28
Square, cm2	0,79	1,77	3,14	1,57
Volume, cm3	3,93	8,84	15,71	7,85
Ferroboron mass, g	10,6	17,3	20,9	21,2

*two ferroboron insertion with diameter of 1 cm each

Front of burning thermite mixture move from the top burned surface vertically down. Thermite reaction`s heat flow is distributed in all directions. Restrictions for heat flow are: dry clay-sand mold, thermite mixture, thermite reaction products, and ferroboron insertion.

Dry clay-sand mold has low thermal conductivity and high heat capacity enough, therefor, thermite reaction`s heat losses is minor in this direction. Generally, dry clay sand mold, can be seen as a continuous barrier reflection of heat flow.

Thermite mixture absorbs the heat of thermite reaction. This heat is required for heating thermite mixture components – mainly aluminum powder, and iron oxide. The product of thermite reaction is aluminum oxide, which has a low thermal conductivity. But, a layer of aluminum oxide, on the surface of thermite, is not dense. Part of the heat flow passing out through the thermite reaction products. Thermal properties of materials are shown in Table 3.2.

Thus, the main part of heat flow is directed to ferroboron insertion.

TABLE 3.2 – MATERIALS THERMAL PROPERTIES

Material	Thermal conductivity coefficient, W/(m*K)	Specific heat capacity, J/kg*K
Aluminium	237	880
Sand (mold)	0,35	970
Scaling	1,62-2,3	1050-1253
Reaction product (Al_2O_3)	20-30	0,78

In fact, the thermite reaction progression could be seen as moving of heat source, in a shape of "ring" along ferroboron insertion (Fig 3.1) The heat flow efficiently heats and melts FeB in insertion is directed to the center of the "ring". Accordingly, the heat flow is directed from the outer surface ferroboron insertion to its center. Consequently, the heat flow path in ferroboron insertion is a half insertion diameter.

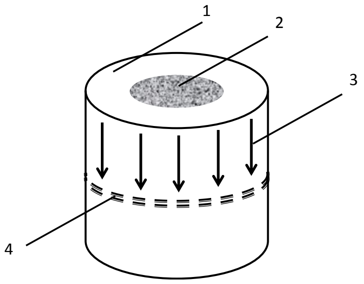

Fig. 3.1 Scheme of the thermite reaction progression 1- thermite mixture, 2 – ferroboron insertion, 3 – the direction of the thermite reaction progression, 4 – conventional thermite reaction frontline

For ferroboron insertion geometric dimensions and variable thermite mixture size were determined: heat flow path in ferroboron insertions with different diameters, thermite mixture "ring" width and their ration. In turn, this allows to define the geometric rations and conditions, affecting the thermite reaction kinetics moving and ferroboron insertions melt.

Table 3.5 given ratio of width termites "ring" in the mold to the heat flow path, which is ferroboron melting parameters.

TABLE 3.3 – GEOMETRIC CHARACTERISTICS OF "TERMITE - FERROBORON INSERTION" SYSTEM.

Ferroboron insertion diameter d, cm	1	1.5	2	1+1
Heat flow path R, cm	0.5	0.75	1	0.5
Thermite width D, cm	2	1.75	1.5	1.75*
Ration, D/R	4	2.33	1.5	3.5*

*averages

Figure 3.2 presents possible schematic diagrams of heat flow moving geometrical characteristics for ferroboron insertions with a diameter of 1 cm, 1.5 cm, 1 + 1 cm and 2 cm.

With a constant outer thermite diameter of 5 cm and changing the ferroboron insertion diameter from 1 to 2 cm, the heat flow path ranges is from 0.5 to 1 cm, thermite`s "ring" width is from 2 to 1.5 cm. The ratio of thermite width to the length heat flow path D/R are 4 to 1.5, respectively.

For insertion with diameter of 1 cm heat flow path is 0.5 cm, thermite`s "ring" width is 2 cm (Fig.3.2.a). Under such conditions the heat flow path – the smallest and the amount of released heat – the largest. The ratio of thermite width to heat flow path length D/R is 4. There is a complete ferroboron melting.

At insertion diameter of 2 cm the heat flow path is 1 cm thermite "ring" width is 1.5 cm (Fig.3.2.c). Under such conditions the heat flow path – the largest and the amount of heat released – the smallest. The ratio of thermite width to heat flow path length D/R is 1.5. Complete ferroboron melting not occurs.

When insertion diameter is 1.5 cm heat flow path is 0.75 cm, thermites "ring" width is 1.75 cm (Fig.3.2.b). The ratio of thermite width to heat flow path length D/R is 2.33. There is a complete ferroboron melting.

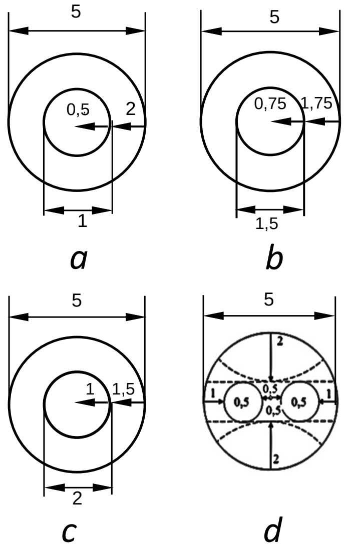

Fig. 3.2 Heat flow moving geometric characteristics at insertion diameter a) 1 cm; b) 1,5 cm; c) 2 cm; d) 1+1 cm.

At the D/R rations 4 and 2.33 complete ferroboron melting occurs. And at the D/R ration 1.5 – were melted only 78 ... 83 % of ferroboron. So, for ferroboron insertion with diameter of 2 cm is insufficient heat to fully melting. For ferroboron insertion with diameter of 2 cm a heat flow path is equal to 1 cm and it is not enough for heating and complete melting (at a fixed thermite diameter)

For conservation of ferroboron quantity instead of one insertion with a diameter of 2 cm was used two insertions with a diameter of 1 cm each (Fig.3.2.d). The insertions are placed on axis at the distance of 1 cm apart. So on the insertions setting axis the thermite`s “ring” width was lowest and amounted to 1 cm. In general, the use of two feroboron insertions a termites "ring" width is variable and is in interval of 1-2 cm. Heat flow path is 0.5 cm, and ration D/R of thermite width to heat flow path length is in the range from 1 to 4. The average value is 3.5. This ratio provides a complete ferroboron melting.

Calculated and analyzed rations of the thermite "ring" width to the heat flow path length in ferroboron insertion lead to the conclusion that the ration D/R in the range of 2.3 – 4 provided conditions complete ferroboron melting (Fig 3.3).

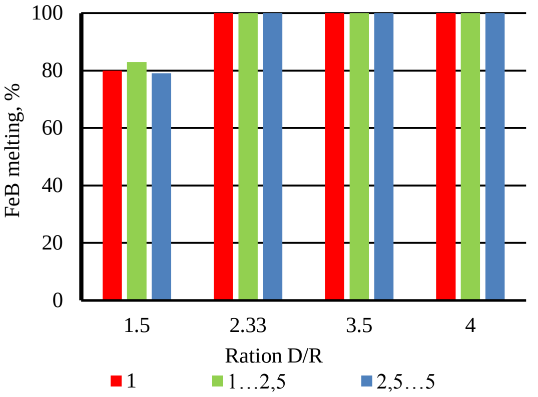

Fig. 3.3 Ferroboron melt percentage at different ratio D/R value.

Thermite reaction flow time is increased with decreasing ratio D/R regardless of fractional composition ferroboron insertion (table 3.1 and fig. 3.4).

TABLE 3.4 – THERMITE BURNING TIME AT DIFFERENT RATION D/R AND FERROBORON FRACTION

Ferroboron fraction, mm	Burning time(s) at Ration, D/R			
	1,50	*2,33*	*3,50*	*4,00*
1 mm	68	37	14	14,2
1…2,5 mm	49	14	11	11
2,5…5 mm	59	37	16	11,9

The difference of fractions impact observed in the following: for a fraction of 1 ... 2,5 mm thermite reaction progression time sharp increasing (about 4 times) was registered only at values D/R ration less than 2.33, however for ferroboron fractions of 1 mm and 2.5...5 mm of sharp increasing of the thermite reaction burning time (about 3 times) was registered at ration D/R less than 3.5.

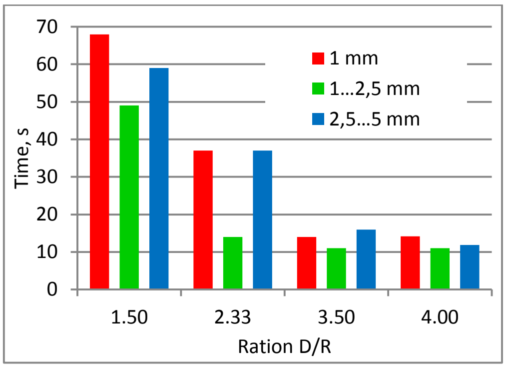

Fig. 3.4 The influence of the ratio D/R on a thermite reaction progression time.

4 MATHEMATICAL MODEL

Mathematical models are built on condition that the ratio D/R provides complete ferroboron insertions melting. Mathematical models describe the influence of the ratio D/R at the thermite reaction burning time for each ferroboron faction (table 4.1).

TABLE 4.1 – MATHEMATICAL MODELS OF THERMITE REACTION PROCESSION TIME.

Ferroboron faction	Mathematical models	Reliability, %
≤ 1 mm	$t = 33.868(D/R)^{0,929}$	86
1…2,5 mm	$t = 13.703(D/R)^{-0,233}$	87
2,5…5 mm	$t = 35.925(D/R)^{-1,052}$	98

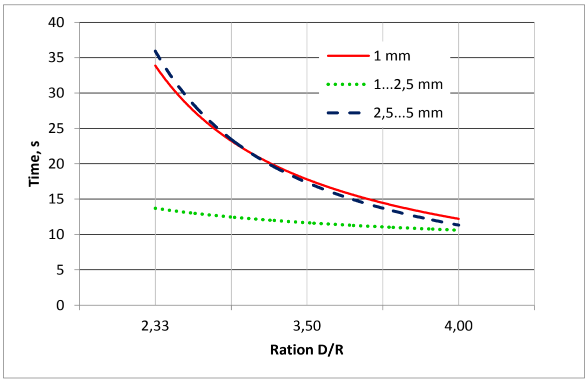

Fig. 4.1 The influence of the ratio D/R on a thermite reaction progression time.

5 CONCLUSION

- For quantify characteristics of the ferroboron insertion melting process and thermite reaction flow should be used integral parameter, which is the ratio of the thermite width to the thermite heat flow path length (D/R).
- Complete ferroboron insertion melting occurs at the ratio D/R value is not less than 2.33.
- For a complete melting of large quantities of ferroboron should be used not one, but several insertion with smaller diameter for provide ratio D/R not less than 2.33.
- Controlling integral parameter value in the range of 2.33 – 4 allows to adjust the burning time at the range of 10 – 70 seconds and consequently amount of alloy element in cast iron parts.

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