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Ferroborron Melting Kinetics in Thermite Mixture

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***Abstract* — Cast parts with differentiated features significantly reduce operating costs but their production connected always with difficulties. Direct use the in-mold process for alloying cast iron with high temperature ferroalloys is not possible because their low dissolution. Dissolution process can be intensifying with thermites mixture. The thermite burning time as a function of ferroboron fraction and ferroboron insertion diameters were investigate. Ferroboron fractions were in a range 1..5 mm. Ferroboron cylindrical insertions diameter were 10, 15, 20 mm. The conditions and characteristics of ferroboron-thermite system, which is achieved complete melting of ferroboron were investigated.**

Keywords— Double-Layer Casting Part; In-Mold Process; Iron Aluminum Thermite Burning Kinetics; Ferroboron Melting Kinetics.

I INTRODUCTION

1.1. Production of doubl-layer castings

In condition of impact-abrasive wear long-term operation of machines and mechanisms provide details of shockproof viscous core and durable working surface layer.

In [1,2,3] was proposed differentiation properties of individual cast parts by separating cast iron melt in two streams. During mold pouring it is possible to treat these flows by different functional purpose modifiers.

1.2. In-mold process

The idea of in-mold process is to treat cast iron in the gating system, in the containing modifier reaction chamber.

The modifier dissolving process in liquid cast iron comprises the steps of heating, melting and dissolving itself [4].There are many advantages and of this technology.

Transition modifying elements kinetics from modifier to liquid cast iron is limited by the speed of the heat flow and mass transfer processes. In conditions of intensive forced movement of the melt in the reaction chamber is convective heat transfer, heat flow density ***q*** in specific time on modifier particles surface can be calculated by Newton-Richmann law:

$$q = \alpha(T_L - T_S)F \qquad (1)$$

where: α - heat transfer coefficient;

T_L – melt temperature

T_S – modifier particles surface temperature;

F – modifier particles contact surface with melt

The process of dissolution in nature refers to physical and chemical processes, but the mathematical theory of diffusion transfer apparatus similar to the apparatus of heat transfer. Number of modifier ***M***, which is dissolved in the liquid cast iron per specific time is calculated by Shchukarev law [5,6].

$$M = \beta(C_{iS} - C_{iL})F \qquad (2)$$

where: β - mass transfer factor;

C_{iS} – specific density i-component in modifier;

C_{iL} – specific density i-component in liquid cast iron;

F – dissolving modifier particles surface

The main factor that limits the rate of heat and mass transfer processes in the in-mold process is the surface value F of interfacial interaction melt and granular modifier. Features of heat and mass transfer processes intensification by global increasing the melt temperature or increasing in modifier specific elements concentration are very limited or not feasible. Increasing melt contact surface with granular modifier is one of the main factors that determine the kinetics of transition modifying or alloying elements into cast iron during alloying or modification in the mold.

But, using modifiers or alloying elements with melting temperature higher than temperature of pouring cast iron, time of dissolution process far exceeds the mold filling time, due to very small values of mas transfer. Increasing contact surface virtually no effect on dissolution.

The intensification of the process is possible by local cast iron heating in the mold or melting high temperature ferroalloys in mold with thermite mixtures.

1.3. Thermite mixture

Thermite basis in most cases is iron oxide (FeO, Fe_2O_3, Fe_3O_4), and for special purposes – CuO [7].

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

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.

In foundry thermite mixture is use in steel castings risers, heated by means of exothermic reactions and in some other cases [8].

The characteristic features that distinguish the process of burning termite from other pyrotechnic mixtures are:

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

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

1.4. Stabilaizing additives

Manganese, chromium, boron are stabilizing elements that make cementite resistant to decay.

Manganese is mostly use to stabilize pearlite matrix. Together with other elements it is used for chilled structure. The content of manganese in cast iron is 0.7 … 4%. Efficiency dissolving ferromanganese in the cast iron flow is depended on pouring temperature, faction, shares space reaction chamber filling speed and mass [9,10].

Boron in a small amount (0.003%) forms in cast iron includes of very soft phase BN, which is almost isomorphic graphite [11]. This phase can act as graphitization centers (topotaxy effect).

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.

Increasing the boron content to 2% in hypereutectic cast iron leads to changes in primary forms carbide crystals to the three-branched These morphological changes are observed and in hypoeutectic cast iron [16].

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

- For producing casts with double-layer chilled surface expedient use boron.
- Ferroboron, practically, is insoluble in cast iron flow (melting point is 1389...1540°C). For creation ferroboron melting and dissolving conditions there are appropriate using thermite mixtures.
- Iron aluminum thermite forms a liquid slag, which is a significant advantage at cast iron treating in the reaction chamber in casting mold.

The purpose is to study the ferroboron melting kinetics among aluminum termites.

To achieve this goal it is necessary to set the regularities of ferroboron fraction and its amount on front thermite reaction moving speed and ferroboron melting efficiency.

2 MATERIALS AND METHODS

2.1 Mold

For the ferroboron melting kinetics among iron aluminum thermites study was used an open dried 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.

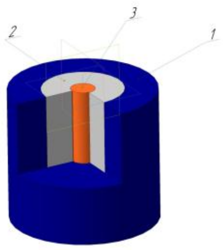

Fig. 2.1 Sand mold for investigation. 1 – sand mold; 2 – iron aluminum thermite; 3 – ferroborron insertion.

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 Ferroboron fractional composition influence on thermite burning time.

With increasing ferroboron insertion grains (particles) size from 1 to 5 mm is observed extremal dependence of iron aluminum thermites burning time. Ferroboron insertions specifications and general results are presented in Table 3.1.

TABLE 3.1 FERROBORON INSERTIONS SPECIFICATIONS AND THE GENERAL RESULTS.**

Fractional composition, mm	Burning time, s			Thermite mass, g			Insertion mass, g		
	Ferroboron insertion diameter, cm								
	1	1,5	1+1	1	1,5	1+1	1	1,5	1+1
≤ 1	14	37	14	150	110	70	11	26	23
1…2,5	11	14	10	146	100	70	11	22	20
2,5…5	12	37	16	149	105	78	10	22	20

**When insertion diameter was 2 cm thermite reaction time was 68, 41 and 59 sec, respectively, but complete ferroboron melting not happened, regardless of fraction.

At increasing particles size from ≤1 to 1…2,5 mm burning time goes down, and further increasing particle size to 2,5…5 mm burning time goes up.

At fractions ≤1 mm pores size of ferroboron insertion are relatively small, resulting the slow distribution of heat flow inside insertion. The burning time is at the range 14…68 seconds. At fractions 2,5-5 mm pores size of ferroboron insertion are biggest, at the experiment conditions, resulting quick distribution of heat flow inside insertion, but the pieces are so large and it is need a lot of time for melting.

The burning time was in the range 12…59 seconds. The shortest thermite burning time, with full ferroboron melting, observed at fractions 1...2.5 mm. This is due to the fact, that the pores size provides adequate penetration of heat, which is necessary for rapid ferroborn particles melting. The burning time was in the range 10…49 seconds (Fig. 3.1).

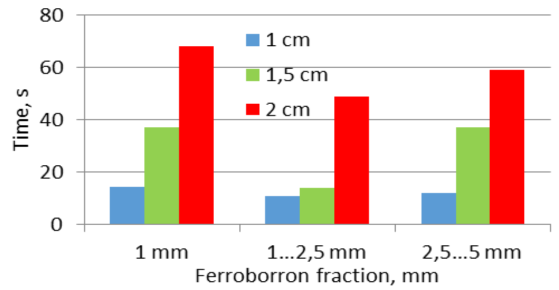

Fig. 3.1 Effect of ferroboron fractional composition on the thermite burning time

Increasing ferroboron insertion diameter increased thermite burning time and led to uncomplete ferroboron melting. The dependence has monotonically growing character for each ferroboron fraction. At fraction composition ≤1 mm burning time grows rapidly than at another fraction. At diameter of 1 cm it is 14 seconds and at diameter 2 cm it is 68 seconds (near 5 times).

Slowest burning time growing is observed at ferroboron fraction composition 1…2,5 mm (Fig.3.2). Increasing ferroboron insertion diameter increased heat flow path inside insertion. Ferroboron insertion has possibility to absorb more thermite reaction heat per specific time and to decrease reaction temperature. The reaction rate between iron scale and aluminum reduces and therefore the reaction time is increased. The dependence has near liner character.

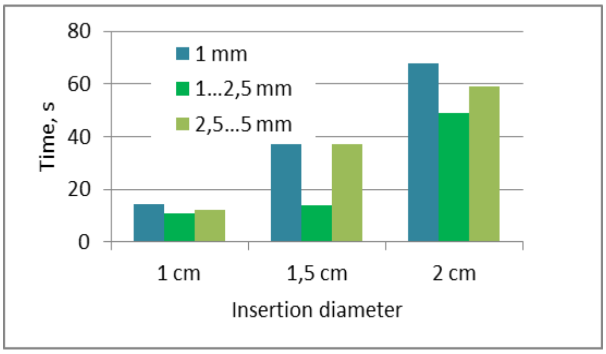

Fig. 3.2 Effect ferroboron insertion diameter on thermite burning time.

Ferroboron insertion with a diameter of 2 cm, didn't melt completely regardless of faction. Therefore, it was used two insertions, with a diameter of 10 mm each with the near same ferroboron mass instead of one insertion with diameter of 2 cm. Ferroboron insertions and iron aluminum thermite specifications are presented in Table 3.2.

Two insertions showed high efficiency ferroboron melting at all fractions. The burning time is at the range from 10 to 14 seconds depending on ferroboron fraction (Fig 3.3). Two insertions burning time much the same as one insertion with diameter 1 cm but ferroboron quantity is increased doubled.

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TABLE 3.2 FERROBORON INSERTION AND IRON ALUMINUM THERMITE SPECIFICATION.

Insertion high, mm	Insertion diameter, cm	Insertion mass at ferroboron fraction, g			Average thermite mass, g
		≤1	*1…2,5 mm*	*2,5…5 mm*	
50±1	1	11	11	10	148
50±1	1,5	26	22	22	105
50±1	1+1	23	20	20	73
50±1	2	23	20,5	19,6	72

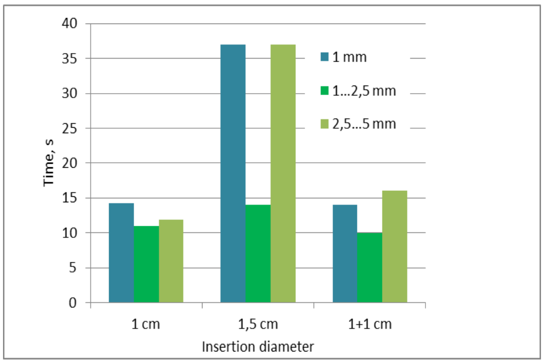

Fig. 3.3 Effect ferroboron insertion diameter on thermite burning time (it was use two insertions with 1 cm diameter instead of one insertion with 2 cm diameter).

5 CONCLUSION

- Thermite reaction front moving significantly depends on the fractional composition of ferroboron and insertion diameter.
- The fractional composition dependence has extreme character. The shortest time is at ferroboron fraction 1...2.5 mm and is 10...14 seconds. Reducing or increasing the size of the particles, increases thermite reaction time moving up to 40 seconds, depending on insertion diameter.
- Increasing ferroboron insertion diameter from 1 cm to 2 cm led monotonically increasing thermite burning time in more than 5 times. Insertion with diameter of 2 cm couldn't permit to melt all ferroboron. Two insertions with diameter 1 cm instead of one insertion with diameter of 2 cm with the same mass permits decrease burning time and full ferroboron melting.

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