https://doi.org/10.18321/ectj704

Effects of Changing Size-Weight Parameters on the Temperature Dependent Exothermic Riser Sleeve Properties

O. Yücel[1], A. Turan[2*], K.C. Candeğer[3]

[1]Metallurgical and Materials Engineering Department, Faculty of Chemical and Metallurgical Engineering, Istanbul Technical University, 34469, Maslak, Istanbul, Turkey
[2]Chemical and Process Engineering Department, Faculty of Engineering, Yalova University, 77200, Yalova, Turkey
[3]Smart Engineering, 69006, Zaporozhye, Ukraine

Received:
4 June 2017

Received in revised form:
19 September 2017

Accepted:
27 November 2017

Abstract

Exothermic riser (feeder) sleeves are used to retain the heat in risers and to increase solidification duration. A riser should be enough hot to become the last solidified part in a mould cavity. Thus, risers can feed the other parts to result in sound casting products without cavity like defects. They are particularly preferred for steel and ductile iron casting operations which have high pouring temperatures. Exothermic riser sleeves are a mixture of metallothermic-based exothermic and insulating materials (Al, Fe_2O_3 and SiO_2 etc.) that are manufactured in different sizes and shapes. In the present study, performances of some selected commercial sleeves were evaluated in terms of reaction duration, flammability and temperature change etc. Some thermochemical modelling studies were performed to understand the effect of reactant composition on sleeve performance prior to the performance tests.

1. Introduction

Casting is a manufacturing method of metal products which is basically based on the pouring of molten metal into mould cavity to shape same as the cavity or pattern (in a more technical language) after solidification. Pouring temperatures of metal and metal alloys are higher than their melting temperatures to ensure that mould cavity is fully filled by molten metal before the commencement of solidification and, that phenomenon is called “superheat”. Two types of shrinkage take place during solidification of casting products and, those are called “liquid shrinkage” and “solidification shrinkage”. Liquid shrinkage happened during the cooling down of molten metals to solidification temperature. Density of metal increases due to the decrease of molten metal volume. It was reported for cast irons that volume decrease ratio is about 1.1% of volume for each 100 °C fall of temperature. Solidification shrinkage takes place in the phase transformation from molten phase to solid state having crystal structures. The sum of liquid shrinkage and solidification shrinkage is used to calculate how much excess molten metal will be poured into mould cavity prior to the pouring to have sound casting products without cavity like defects. The summation of those shrinkage mechanisms is called “total liquid shrinkage” and it may change in accordance with the type of alloy referring to their different chemical compositions and their phase transformations during solidification. Detailed information, concerning the effects of chemical compositions on total liquid shrinkage, can be found in the literature. Nevertheless, for instance, total liquid shrinkage of grey cast iron which has a carbon content of between 3.4–4.0% and is poured at 1350 °C is about 0.6% whilst that value is 7.25% for white malleable cast iron which is poured at 1510 °C [1].

Next definitions and technical approach are mainly given for sand casting practice. Sand moulds consist of upper part called “cope” and lower part called “drag”. In cope and drag, there are cavities as the patterns of casting product, gating and risering systems. Gating system containing sprues is the set of cavities where molten metal is first poured into moulds and, it directed molten metal into main mould cavity whereas a risering system (or riser) is the final part of a mould cavities

*Corresponding author. E-mail: aturan@yalova.edu.tr

to solidify. Therefore, risers (or feeders) feed other parts of casting products which solidify priorly. Thus, casting products without cavities can be obtained. Risers and sprues are cut off after the fully cooling down of casting products [2–6]. Accounts in the literature state that riser weight should be 2.5 times higher than the feed requirement of casting product for circular risers. However, surface area of a riser is another important parameter to consider. Smaller surface area for the same mass values results in higher solidification duration. Spherical risers have the lowest surface area/weight ratios as well as the highest solidification duration [1]. Detailed analytical calculations about the dimensions and positions of risers were previously studied and released by some well-known scientists such as Wlodawer [7, 8].

Sometimes, it is necessary to use insulating or exothermic sleeves around risers to extend solidification duration particularly for steel or ductile iron casting. Exothermic riser sleeves are made of powder mixtures which give exothermic (thermit) reactions. Plenty amount of heat is thereby produced to keep risers hot. Those sleeves have heat-sealing properties superior to those of insulating sleeves and unsleeved risers [1, 2, 8–10]. Exothermic riser sleeves are composed of a mixture of metallothermic-based exothermic materials and insulating materials such as Al, Fe_2O_3 and SiO_2. The main reactions providing heat are given as Eq. (1) which is called the "Goldschmidt Reaction" and as Eq. (2) and, they are both exothermic reactions [1, 9].

$$2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2Fe \tag{1}$$

$$2Al + 3/2O_2 \rightarrow Al_2O_3 \tag{2}$$

It has been stated in the literature that riser sleeves can increase solidification time by nearly 50% and they retain up to 30–35% of the heat from casting. Exothermic sleeves are in the market in different sizes and shapes such as cylindrical, oval cylindrical, conic etc. Exothermic riser sleeves are sold under their commercial names with changing chemical content ratios. Manufacturers usually just share their basic properties in product specifications. It is necessary for designers who design mould systems containing gating and risers should know their themochemical and thermophysical properties to enhance their designs [11–13].

In the literature, the number of studies on the properties of exothermic (or insulating) riser sleeves is limited. Studies about riser sleeves in the literature have not comprehensively concerned their performance tests and direct use. In 2000, Smith et al. reported the results of a study on the application of new feeding rules which had been developed by the SFSA (Steel Founders' Society of America) to risering of steel castings. They also used riser sleeves in some of their models. Preliminary results of a study about the effects of sleeve type on casting yield were released in 2013 by Hardin et al. They stated that exothermic sleeves increased the time to solidus by 44% when it is compared to unsleeved 7 inch (17.78 cm) diameter riser during the solidification.

In the present study, selected commercial exothermic sleeves were tested to determine their temperature dependent properties such as reaction duration, flash point and temperature change as a function of the weight-size of the sleeves. The experimental results were compared to each other and thermodynamical simulations which were conducted prior to the experiments.

2. Theoretical background

The "Goldschmidt Reaction" which was given as Eq. 3 is the main reaction in exothermic sleeves. After reaction, the composition of products change in accordance with the change in the aluminium ratio in reactants. Aluminium reduces iron from iron oxide up to the stoichiometric ratio. If there is excess aluminium (much more than the stoichiometric ratio to reduce iron), silicon may be reduced under the prevailing conditions. Wlodawer suggested two different exothermic riser sleeve initial compositions which are showed in Table 1 with their respective thermodynamic properties. Those compositions were codded as A and B and, details can be found elsewhere [8]. They change in terms of Al content and, their corresponding thermochemical properties were calculated by using HSC Chemistry 6.12 database.

$$Fe_2O_3 + SiO_2 + Al_2O_3 + Al \rightarrow Fe + Fe_2O_3 + SiO_2 + Al_2O_3 \tag{3}$$

Products were thermodynamically predicted for the reactant compositions A and B and, their equilibrium compositions were plotted as a function of temperature in Fig. 1. It is evident that the metallic silicon and aluminium content of the products increase due to the increase in aluminium in the reactants. After nearly 1700 °C for the composition B, a slight amount of SiO_2 appears in reaction products.

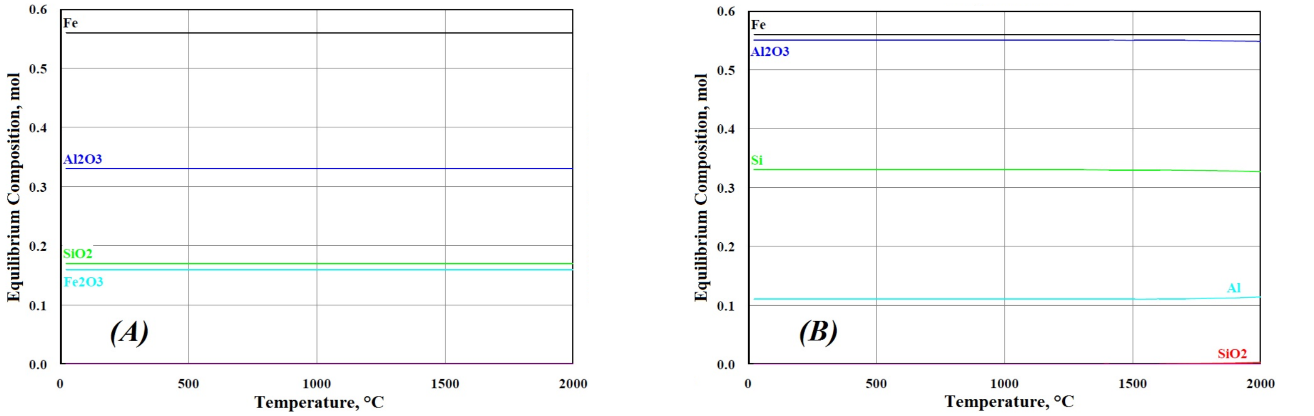

Fig. 1. The change of reaction products for the compositions (A) and (B) with the increase in reaction temperature (HSC Chemistry 6.12, Equilibrium Compositions Module).

Table 1
Suggested exothermic riser sleeve contents in the literature (Wlodawer, 1966) and their calculated thermodynamical properties (HSC Chemistry 6.12, Reaction Equations Module)

No	Content, wt.%				ΔG^0, kJ	ΔH^0, kJ	Specific Heat, J/g
	Fe_2O_3	SiO_2	Al_2O_3	Al			
A	70	10	5	15	-235.544	-238.753	-2387.5
B	45	20	5	30	-301.018	-306.823	-3068.2

3. Experimental

Five commercial exothermic riser sleeves which were manufactured by Smart Engineering (Ukraine) were used for the experimental studies. Shapes, diameters and weights of the exothermic riser sleeves were shared in Table 2. Four of sleeves were cylindrical and the other had an oval cross-section.

Sleeves were put in a muffle furnace which was maintained at 1000 °C and under atmospheric pressure. The change of sleeve temperature vs. (increasing) time was recorded to document the flash point, reaction duration and the highest temperature. The sleeves were removed from the furnace after they had cooled to 1000 °C. Photographs which were taken prior to the experiments and during the experiments can be seen in Fig. 2.

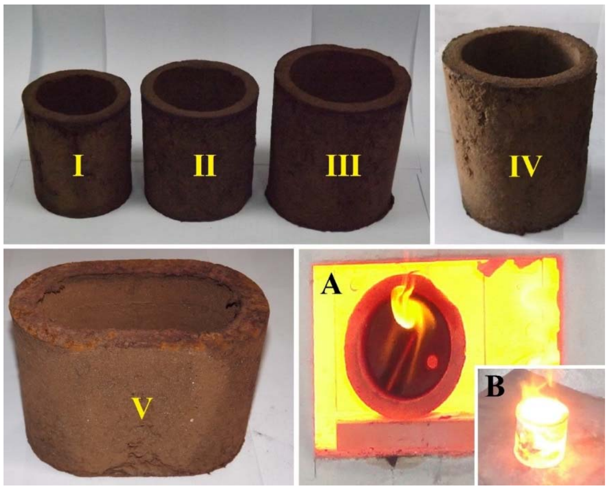

Fig. 2. Photographs of exothermic riser sleeves before performance tests and during tests; (A) riser sleeve in the muffle furnace, (B) riser sleeve during cooling period.

Table 2
Shapes, dimensions and weights of exothermic riser sleeves which are used in experimental studies.

No	Shape	Outer Diameter (mm)	Inner Diameter (mm)	Outer Diameter^2 (mm)	Inner Diameter^2 (mm)	Height (mm)	Weight (g)
I	Cylindrical	94.0	69.5	-	-	99.0	230.0
II	Cylindrical	102.0	79.0	-	-	108.0	310.0
III	Cylindrical	115.0	89.0	-	-	120.0	400.0
IV	Cylindrical	127.0	97.0	-	-	133.0	620.0
V	Oval Cylindrical	200.0	160.0	120.0	80.0	150.0	800.0

4. Results and Discussion

The sleeves started to burn once they were put in the muffle furnace. It is the proof of that the furnace temperature (1000 °C) was higher than the flash point of the sleeves. Maximum reaction temperature ranged from 1352 °C to 1670 °C; for cylindrical sleeves in particular, it was determined that the higher reaction temperatures were attained as the sleeve weight increased. The reaction duration and the cooling period were also with increasing sleeve weight. An exception was the cooling duration of the sleeve coded (IV). Although sleeve (IV) exhibited the highest reaction temperature of the cylindrical sleeves, it cooled more rapidly than two lighter sleeves, which were coded (II) and (III). It is believed that the rapid cooling was due to structural degradation caused by the very high reaction temperature (Fig. 3, Table 3).

The sleeve coded (V) had the greatest mass (800 g). This sleeve retained more heat than the other specimens; its peak temperature of 1505 °C was lower than those of the lighter sleeves, and it cooled to below 1000 °C in 15 min. The experimental results provide evidence that increasing sleeve weight increases the peak temperature and extends the cooling period due to surface effect. Because the solids lose heat from their surfaces, increased mass decreases the specific surface area for heat loss, thereby accounting for the greater degree of heat retention.

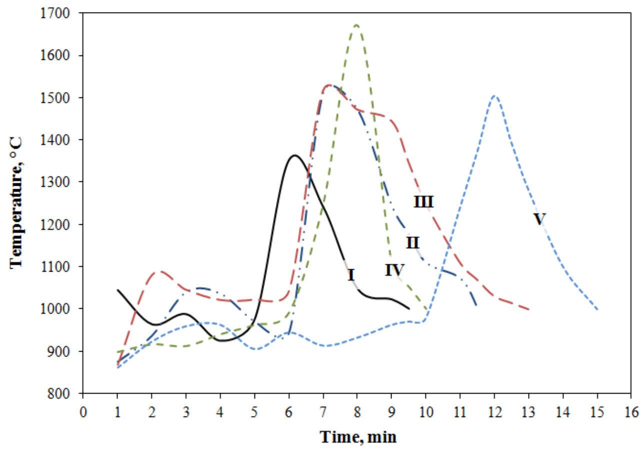

Fig. 3. The relationship between size-weight of the sleeves and reaction time.

Table 3
Thermal and chemical properties of the sleeves measured during the experiments.

No	Flash point, min	Reaction beginning time, min	Cooling time below 1000 °C, min	Highest temperature during reaction, °C
I	At the start	5 min 55 sec	9 min 30 sec	1352
II	At the start	6 min 17 sec	11 min 35 sec	1513
III	At the start	6 min 27 sec	13 min 0 sec	1517
IV	At the start	6 min 50 sec	10 min 2 sec	1670
V	At the start	11 min 5 sec	15 min 0 sec	1505

5. Conclusions

Exothermic riser sleeves are used to increase the solidification time of risers in sand casting operations. It is thereby guaranteed for risers to be the last solidified part between casted metal products containing gating parts. Thus, sound casting products that do not have cavity-like defects can be obtained. Exothermic riser sleeves consist of an exothermic reactant powder mixture (mainly Fe_2O_3 and Al) to retain heat in the riser part of castings by providing an exothermic reaction during casting operation. In the present study, five different commercial sleeves, in terms of size and shape, were evaluated to determine their temperature dependent properties.

Thermochemical modelling was done prior to the experimental studies by using HSC Chemistry 6.12. It was determined that increasing percentage of aluminium in a sleeve composition elevates the Gibbs free energy, enthalpy and specific heat values. Moreover, metallic silicon and aluminium were predicted to be present in the reaction products as a result of the excess aluminium.

During the experimental studies, it was observed that increasing sleeve weight caused an increase in the peak reaction temperature and extended the cooling duration. Solids lose their heat through their surfaces. Therefore, it was thought that increasing weight decreases the specific surface area of the sleeves. Sleeves having higher weight thereby retain the heat in the riser for longer durations and, the solidification takes longer.

Acknowledgement

The authors thank to Kagan Benzesik (ITU), Mehmet Bugdayci (ITU, Yalova Uni.) and Murat Alkan (Dokuz Eylul Uni.) for assistance in experimental stage.

References

[1]. J.L. Francis, P.G.A. Pardoe, Chapter 15: The Feeding of Iron Castings, in the book: Applied Science in the Casting of Metals (Edited by K. Strauss), Pergamon Press, Oxford, 1970, 467–485. DOI: 10.1016/B978-0-08-015711-5.50026-9

[2]. J.R. Brown, Foseco ferrous foundryman's handbook. Butterworth-Heinemann, Oxford, 2000.

[3]. C.M. Choudhari, B.E. Narkhede, S.K. Mahajan, *Procedia Engineering* 97 (2014) 1145–1154. DOI: 10.1016/j.proeng.2014.12.393

[4]. S.L. Nimbulkar and R.S. Dalu, *Perspectives in Science* 8 (2016) 39–42. DOI: 10.1016/j.pisc.2016.03.001

[5]. M. Upadhyay, T. Sivarupan, M.E. Mansori, *J. Manuf. Process.* 29 (2017) 211–220. DOI: 10.1016/j.jmapro.2017.07.017

[6]. T. Wang, Y. Shan, W. Shen, *J. Mater. Process. Tech.* 222 (2015) 21–26. DOI: 10.1016/j.jmatprotec.2015.02.034

[7]. S. Ou, K.D. Carlson, C. Beckermann, *Metal. Mater. Trans. B* 36B (2005) 97–116. DOI: 10.1007/s11663-005-0010-7

[8]. R. Wlodawer, Directional solidification of steel castings. Pergamon, Oxford, 1966.

[9]. D.R. Allen and M.V. Barlow, Chapter 14: The feeding of steel castings, in the book: Applied Science in the Casting of Metals (Edited by K. Strauss), Pergamon Press, Oxford, 1970, 443–466. DOI: 10.1016/B978-0-08-015711-5.50025-7

[10]. R.W. Ruddle, Chapter 13: Solidification of castings-general principles of feeding, in the book: Applied Science in the Casting of Metals (Edited by K. Strauss), Pergamon Press, Oxford, 1970, 417–442. DOI: 10.1016/B978-0-08-015711-5.50024-5

[11]. URL-1: http://www.ask-chemicals.com (accessed 04.10.17)

[12]. URL-2: http://www.gtpschaefer.de (accessed 05.10.17)

[13]. R.A. Hardin, T.J. Williams, C. Beckermann, Riser sleeve properties for steel castings and the effect of sleeve type on casting yield. Paper presented at the 67th SFSA Technical and Operating Conference, Chicago, IL, USA, 2013.

[14]. D. Smith, T. Faivre, S. Ou, K. Carlson, R. Hardin, C. Beckermann, Application of new feeding rules to risering of steel castings. Paper presented at the 54th SFSA Technical and Operating Conference, Chicago, IL, USA, 2000.