THE ADVANTAGES OF APPLICATION OF THE SPHERIC IMPACT PAD MADE FROM THE ADVANCED MATERIAL FOR THIS APPLICATION

[1]Branislav BUĽKO, [1]Peter DEMETER, [2]Ivan PRIESOL [1]Slavomír HUBATKA, [1]Lukáš FOGARAŠ, [1]Jaroslav DEMETER, [1]Martina HRUBOVČÁKOVÁ

[1]Technical University of Košice, Faculty of materials, Metallurgy and Recycling Department of Metallurgy, Institute of metallurgy, Košice, Slovak Republic, EU, Branislav.bulko@tuke.sk

[2]IPC REFRACTORIES s.r.o., Košice, Slovak Republic, EU, ipc@ipc.sk

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Abstract

To meet the increasing cleanliness requirements in conticast steel production, innovative solutions must be developed. The tundish, which serves as the final refractory-lined reactor, provides ample space to eliminate inclusions through optimization of the steel flow. The key component of the tundish is the impact pad, which determines the flow pattern of steel and is a crucial element of tundish metallurgy. To prevent the formation of dead zones and slag eyes in the slag layer surrounding the ladle shroud, the optimal steel flow within the tundish must facilitate the removal of inclusions through reactions at the steel-slag interface. Additionally, the flow must prevent excessive erosion of the tundish refractory lining. This study compares the standard impact pad with the spherical impact pad using physical modeling, evaluating the residence time and flow within the tundish at three different casting speeds.

Keywords: steel, spheric impact pad, continuous casting, tundish, physical model

1. INTRODUCTION

Currently, over 96 % of steel production worldwide involves continuous casting, putting increasing pressure on manufacturers of refractory materials used in the process [1]. With the growing proportion of high-grade steel in product portfolios, development in tundish metallurgy is becoming increasingly important. Properly functioning slag systems require controlled steel flow in the tundish to allow inclusions to be released into the slag and chemical reactions to occur effectively at the steel-slag interface [2]. Geometric adjustments to the steel impact point in the tundish are typically achieved using an impact pad, which also helps reduce erosion of the tundish refractory lining [3-5]. The high kinetic energy of the incoming steel creates swirl flow at the point of impact, and a suitably shaped impact pad can create a "piston flow" area, which is an essential indicator of flow adjustment quality. The residence time of steel particles in the tundish is a crucial factor in achieving high-quality flow adjustment [6]. Impact pads have undergone significant development in recent years, with increasingly sophisticated shapes based on mathematical and physical modelling [7-9]. The impact pad is typically used in conjunction with dams, weirs, and baffles to prolong steel residence time in the tundish. This study compares the properties of a spherical impact pad with another types of impact pads without other flow modifiers. The research aims to propose a new, innovative solution for the impact pad using a convex hemispherical shape, which may offer more advantageous steel flow characteristics in symmetrical two-strand boat-type tundishes. The spherical impact pad was designed to reduce the hydrodynamic drag force (1) exerted by the incoming stream of molten steel.

$$F = \frac{1}{2} C \cdot \rho \cdot S \cdot v \qquad (1)$$

where: C - coefficient of drag, ρ - specific mass of fluid, S - size of the reference area (platform area of the pad), and v - relative velocity of impinging stream.

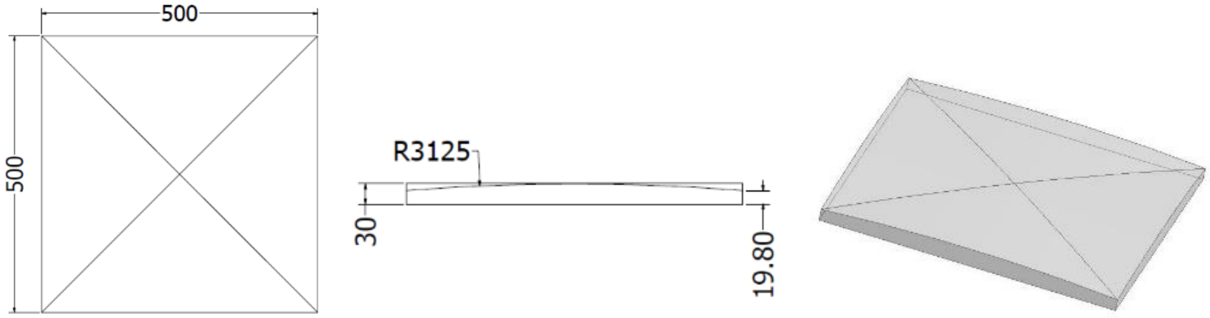

Figure 1 „SPHERIC“ impact pad

The coefficient C quantifies how the shape of the impact pad affects the drag force and is dimensionless and assumed constant for small changes in velocity. Experimental values for drag coefficient of objects in a free stream are 1.17 for a square flat plate and 0.40 for a convex hemisphere. The proposed impact pad has a square platform and the upper surface shape of a large-radius hemisphere, designed to cause less erosion and smaller deflection of the stream, resulting in reduced creation of intense vortices at the surface of the fluid and suppressed short-path flow through more intensive mixing at the core of the fluid volume. A scaled-down physical model of the tundish at a 1:3 ratio, made of transparent plastic (PMMA) with water as the fluid medium, is used for physical modelling and experimentation. The flow of steel in the tundish equipped with the "Spheric" impact pad is optimized not only for residence time, but also for the nature of the flow, promoting the removal of inclusions into the slag and creating ideal conditions for the slag-metal phase interface. This flow modification method is discussed in [12,13].

The drag force of an object is affected by the shape of its pad, which can be quantified using the dimensionless coefficient C. Small changes in velocity do not significantly affect this parameter. Experimental data shows that the coefficient of drag for a square flat plate and a convex hemisphere are 1.17 and 0.40, respectively [10]. The proposed spherical pad, with a square platform and the upper surface shape of a large-radius hemisphere, is expected to cause less erosion and minimize the creation of vortices and short-path flows.

To study the flow of steel in a tundish equipped with the "Spheric" impact pad, physical modelling was performed using a scaled-down model at a ratio of 1:3, made of transparent plastic and water as the fluid medium [7, 11]. The flow of steel was optimized to promote the removal of inclusions and improve the slag-metal phase interface using the method described in [12,13]. Steady-state conditions were maintained during measurements, with a constant level of steel in the tundish and equal amounts of steel flowing in and out of the molds. The C-curve method was used to determine the characteristics of steel flow in the tundish under steady casting conditions [14-16]. Aqueous KCl solution was injected into the ladle shroud, and conductivity probes were used to measure the change in conductivity of the water due to the added salt. From the resulting C-curve, the minimum and maximum residence times (T_{min} and T_{max}) were determined, with T_{min} having a significant effect on the duration of inclusion flow from the steel to the slag [18]. Measurements were performed at various flow rates corresponding to casting speeds of 0.8 $m{\cdot}min^{-1}$, 1.2 $m{\cdot}min^{-1}$, and 1.6 $m{\cdot}min^{-1}$ on a real continuous-casting machine. Each configuration was simulated three times to ensure accurate statistical evaluation and comparison of the results. Mean values were calculated from the measurements for each configuration and used in the results and graphs. After realization of physical simulations using spherical impact pad, we realized that producing such components will require an advanced material that meets stringent criteria. These criteria were established based on current steel production standards in Europe, European legislation, and Industry 4.0 trends.

The primary objectives of our materials research were to develop a material that can withstand long-term exposure to the dynamic environment of liquid steel without deforming the surfaces that control the flow of prefabricated components, particularly those used in the steel inflow area of the tundish. Additionally, we aimed to create a mixture for producing prefabricated components with the lowest possible energy consumption and carbon footprint. To achieve these objectives, we abandoned the idea of producing prefabricated components using LCC and ULCC concrete due to their clear drawbacks, especially regarding points 1 and 2. Instead, we focused our research on preparing cement-free mixtures using a binder created through the sol-gel method. These mixtures demonstrated good resistance to corrosion caused by casted steel.

2. RESULTS AND THEIR ANALYSIS

The implementation of the "Spheric" impact pad was predicted to decrease the residence time compared to the standard impact pad. However, it was also anticipated to reduce the swirling motion of steel around the ladle shroud, which can lead to the formation of the slag "eye" phenomenon. By using the "Spheric" impact pad, it is expected that the mixing area will increase, and the dead zones will decrease. Furthermore, it has been observed that the standard impact pad tends to create a shortcut flow at lower casting speeds. To test the proposed impact pad, we realized experiments on a 1:3 scale water model of a real symmetrical, two-strand boat-type tundish for three different casting speeds. The comparison criteria included the C-curve, residence time, and visual evaluation of the flow in the tundish. We used a water salt solution of KCl as a tracer, and its concentration was measured using a conductivity measurement system. Additionally, we evaluated the flow visually using $KMnO_4$ as a tracer. The results of the simulations comparing the standard and Spheric impact pads are shown in **Figures 2-4**. The flow of tracer at time intervals of 5, 20, and 80 s after tracer injection is presented for visual flow comparison.

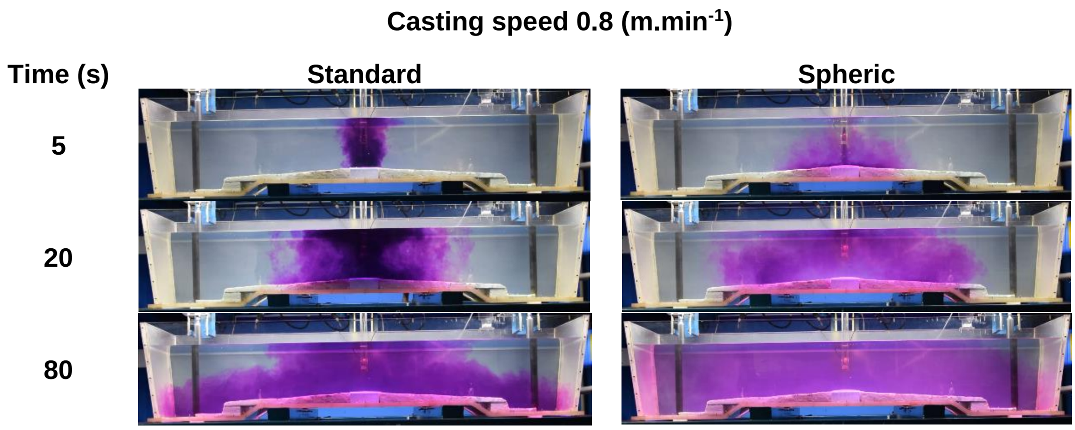

Figure 2 Visual comparison of flow pattern for „Standard“ and “Spheric” impact pad, physical simulation

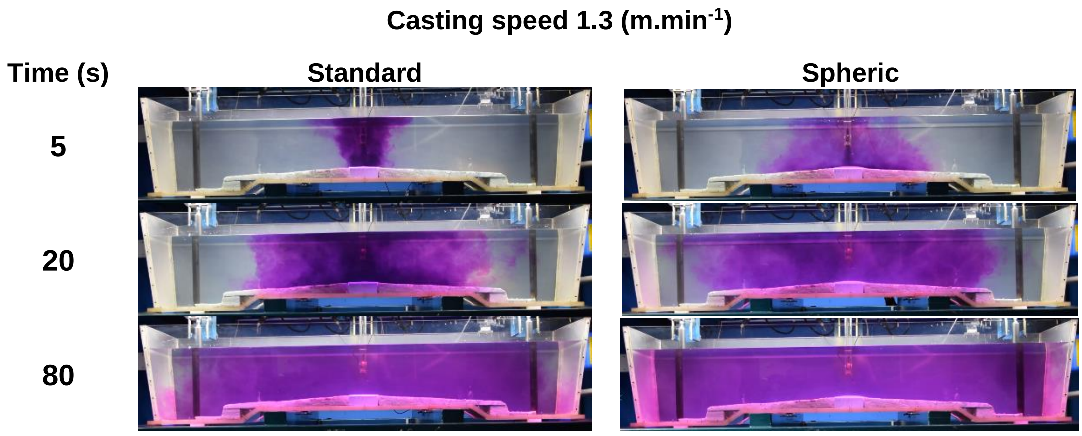

Figure 3 Visual comparison of flow pattern for „Standard“ and “Spheric” impact pad, physical simulation

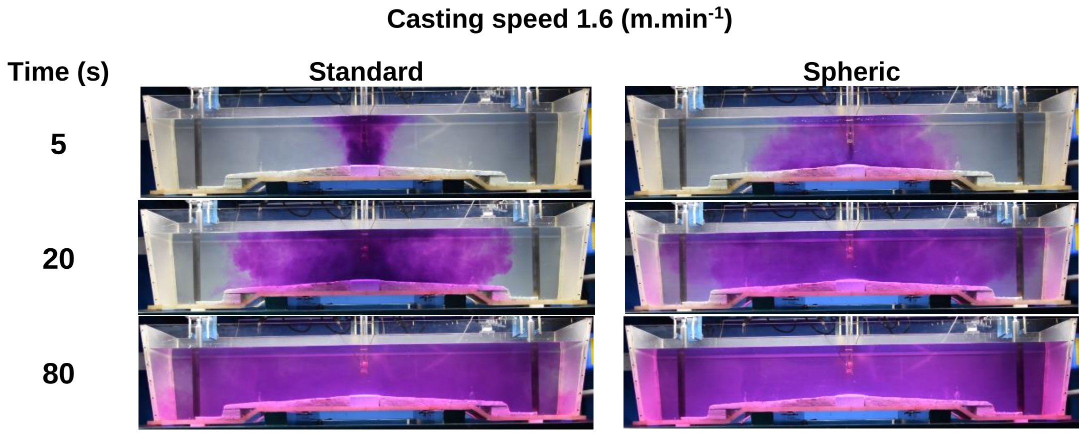

Figure 4 Visual comparison of flow pattern for „Standard“ and “Spheric” impact pad, physical simulation

Table 1 presents a comprehensive comparison of the minimum and maximum residence times for all tested configurations.

Table 1 Comparison of residence times for all tested configurations

Configuration	Casting Speed	Minimal Residence Time (s)	Maximal Residence Time (s)
Standard Impact Pad	0.8 m min^{-1}	50.2	110.3
	1.2 m min^{-1}	40	141.8
	1.6 m min^{-1}	32.8	114.3
Spheric Impact Pad	0.8 m min^{-1}	42.3	133.5
	1.2 m min^{-1}	43.7	120.5
	1.6 m min^{-1}	36.5	84.3

To summarize, the use of a "Spheric" impact pad leads to a lower vertical velocity of steel flow around the ladle shroud compared to a standard impact pad, resulting in the elimination of the slag "eye" phenomenon. To address the disadvantages of classic ceramic materials, two types of sol-gel binders were tested, including a silicate-aluminate colloidal solution prepared in cooperation with VŠB-TU Ostrava, CZ. The sol-gel method allows for control of the purity of input raw materials, stability of composition, and properties of binders, such as microporosity and density. The result of the research is a mixture using a silicate-aluminate binder prepared by the sol-gel method, which has comparable physical properties to LCC/ULCC concretes of an adequate class (bauxite slag) and can form final ceramic phases such as mullite, α-corundum, or cristobalite. The binder was tested at different calcining temperatures, and the samples were analyzed by DT and XRT analysis.

The gel remained amorphous until a temperature of 800 °C. Mullite was observed in the xerogel at 1000 °C, and α-corundum appeared at 1200 °C. Further analysis revealed that mullite formation began at around 950 °C, and the first signs of α-corundum formation were observed at temperatures just above 1100 °C. By lowering the starting temperature of the formation of the final ceramic aluminate phases, mullite and α-corundum, by nearly 100 °C, energy consumption during the final phase transformation can be significantly reduced, which has a positive impact on both the carbon footprint of the concrete and the products made from it. Following experiments with the composition of the final concrete mixture for thixotropic processing, industrial tests were conducted on impact pads with a spherical surface.

Table 2 shows the composition of the mixture, **Table 3** shows the physical properties of the concrete.

Table 2 Composition of concrete mix for flow control precast

Material	wt%
Bauxite 0-6 mm	66
Tabular alumina	15
reactive alumina	14
Si-Al sol-gel binder	5

Table 3 Physical properties of concrete for flow control parts

Properties		Value
Bulk density drying 110°C/2h	(g.cm^{-3})	2.9
Bulk density firing 1200°C/5h	(g.cm^{-3})	2.89
PLC 110°C -ins.500°C	(%)	-0.19
PLC 110°C -fir.1200°C	(%)	-0.11
CCS 110°C/2h	(MPa)	28
CCS 1200°C/5h	(MPa)	122

The concrete properties achieved the objectives of point 1, as demonstrated by their excellent shape stability during the entire casting sequence in practical tests. The tested impact pad was used for casting of 32 heats, each weighing approximately 180 tons, in a sequence that totaled 5.760 tons of cast steel over a period of about 30 hours, without any visible damage or deformation to its surface. The current state of the impact pad after the completion of the sequence can be observed in **Figure 6**, while the application method to the boat-type tundish is depicted in **Figure 5**.

Figure 5

Figure 6

3. CONCLUSION

The development of the "Spheric" impact pad with a convex surface was motivated by the flow differences between a flat plate and a sphere. The implementation of the "Spheric" impact pad in symmetrical, boat-type tundishes provides several benefits including enhanced safety by preventing splashing of steel at the start of casting, creating a more favorable flow pattern, suppressing the "red eye" phenomena, and eliminating dead zones in the tundish. The "Spheric" impact pad is the only known system that distributes the kinetic energy of the impact stream throughout the entire volume of liquid steel, which ensures uniform and identical dynamic flow conditions throughout the casting process. The developed advanced material meets the basic requirement of ensuring the same dynamic flow conditions during the entire steel casting period with a rich reserve. Based on the performed measurements, it can be concluded that the "Spheric" impact pad has enormous potential to optimize the flow of steel in the tundish, and in combination with appropriate "tundish furniture," it can become a new part of modern tundish metallurgy with significant influence on the final quality and cleanliness of continuous cast steel.

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