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Filter effectiveness in the manufacture of high-chromium steel castings

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Abstract

The paper presents the results of studies on the application of ceramic filters in the manufacture of cast hearth plates at the West Pomeranian University of Technology in Szczecin. Castings were poured from the heat-resistant G-X40CrNiSi27-4 cast steel in green sand moulds. The development of casting manufacturing technology included the following studies: analysis of the causes of non-metallic inclusions in high-chromium alloys, computer simulation of mould filling with liquid metal using standard gating systems without filters and new systems with the built-in filter, making pilot castings, quantitative determination of the content of non-metallic inclusions, determination of the oxygen and nitrogen content, and evaluation of the extent of occurrence of the raw casting surface defects. As a result of the conducted studies and analyses, the quality of produced castings was improved, mainly through the reduced content of non-metallic inclusions and better raw casting surface quality.

Keywords: Innovative technologies and materials; Castings from high-alloyed steel; Ceramic filters; Hearth plate

1. Introduction

The ZUT Foundry Research Laboratory in Szczecin specializes in making short batches of heat- and creep-resistant castings in sand moulds. A large share in production profile have the cast plates operating in various types of the heat treatment furnaces [1].

The plates can be of either solid or segmented structure (Fig. 1) with dimensions from 300×600 to 500×1000 mm, wall thicknesses from 10 to 25 mm, and weight from 20 to 100 kg [1]. During operation, these plates are exposed to heavy loads (the charge is placed on them) and to the effect of high temperature (1100^{o}C) with access of atmospheric air. Therefore, the material used most commonly for the hearth plates is the G-X40CrNiSi27 -4 (1.4823) cast steel according to EN 10295:2002.

The technological problem that the manufacturers of this family of cast products have to face is the large number of surface defects (Fig. 2) which need the time-consuming repairs, including the processes of grinding, welding and annealing. The defects identified most often are: folds (W-207), rattails (W-209), slag inclusions (W-212) and sand holes (W-210) (PN-85/H-83105).

Numerous defects spread in groups on the casting surface (Fig. 2) were also observed in cast products manufactured by ZUT Foundry.

In order to reduce, at least partially, the occurrence of severe raw casting surface defects it was decided to investigate what effect the filtration of molten metal might have on thus evaluated quality of castings. The idea was to carry out the filtration process with ceramic foam filter placed in a gating system under the down-gate. The correctness of the idea to use filters was checked through performance of the following tasks:

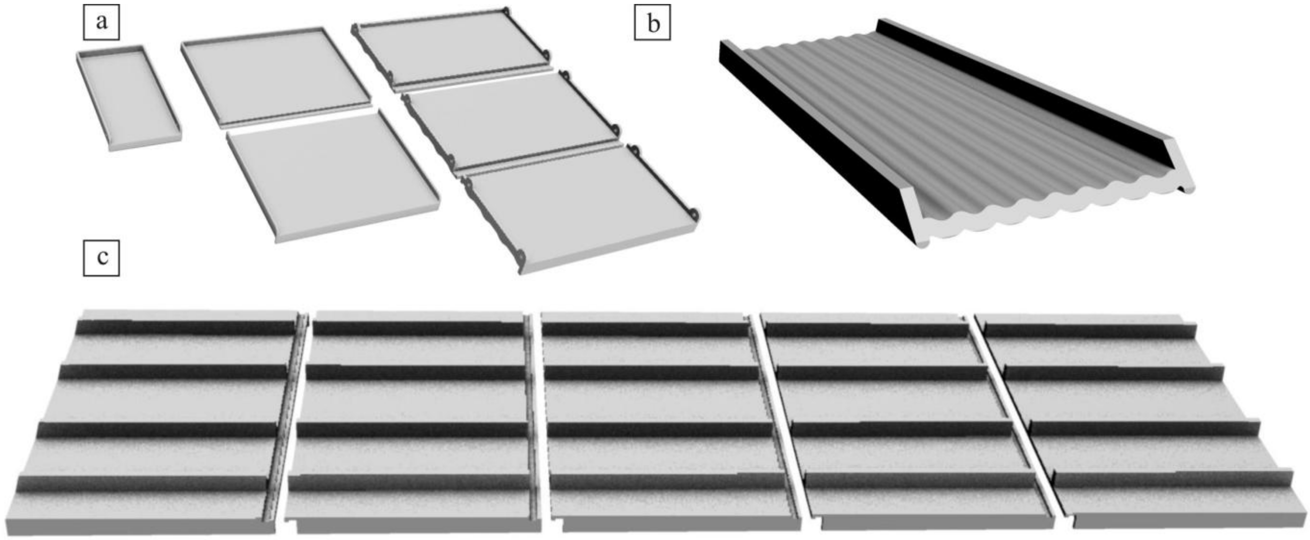

Fig. 1. Drawings of heat-resistant castings made by ZUT Foundry in Szczecin [2]: a) single- and multi-segment hearth plates, b) shaker plate, c) multi-segment plate for walking-hearth furnace

- computer simulation of mould filling with liquid metal, allowing for the novel design with filters placed in standard gating systems used so far,
- evaluation of melt quality and of the number of surface defects in raw castings of the hearth plates made with and without the filter,
- analysis of results.

The scope of studies and analyses as well as the commercial aspects of the whole undertaking do not allow making in this article a detailed summary of all the work done. Despite this, efforts were made to let the examples presented in the article illustrate in a best way possible the research on a technology used to make the selected castings of hearth plates.

At the beginning of studies it was assumed that the use of filters should not require any major redesigning of the gating systems used so far. Their configuration and dimensions were selected by way of numerous experiments, the main aim of which was preventing the deformation of castings during cooling in mould at an assumed metal yield of about 75÷85%.

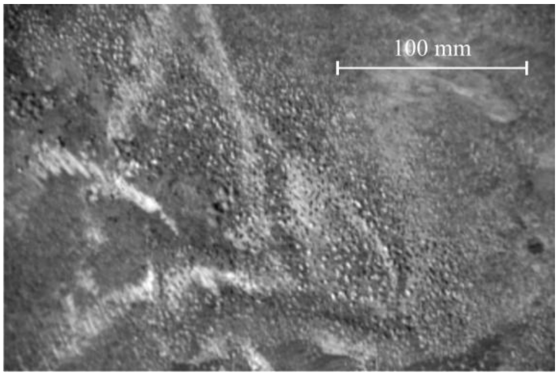

Fig. 2. Typical appearance of surface defects in cast hearth plates [2]

2. Materials, methods and results of tests

2.1. Metal and mould preparation

Cast steel was melted in an electric induction furnace, model IMSK-100, with a rated capacity of 100 kg, powered with current of 2400 Hz frequency. The crucible lining was made from Silica Mix 07 refractory material.

The required chemical composition of the G-X40CrNiSi27-4 cast steel was obtained from the charge composed of medium- and high-carbon ferrochromium, granulated nickel, ferro-silicon and ferro-manganese, low-carbon steel scrap and process scrap. The content of process scrap did not exceed 30%. The melt surface was protected with a coating of glass cullet.

Ladles were lined with Silica Mix 07 material and ZAl60 mortar mixed in a ratio of 1:1. Immediately before use, the ladles were dried and then baked at a temperature of 400^{o}C.

Moulds were made from a homogeneous moulding sand mixture of the following composition:

- silica sand 1K/020/016/010 92,5÷95,5%,
- Zębiec bentonite 4÷6%,
- coal dust 0,5÷1,5%,
- water about 5%.

Earlier trials [3] showed that coal dust addition reduced the occurrence of burn-on defects, oxide films and folds on the surface of castings. Probably, it was due to slightly reducing atmosphere produced in mould on filling it with liquid metal.

Cores were made from a core sand mixture of the following composition:

- silica sand 1K/020/016/010 98,3%,
- SL binder 1%,

– KL catalyst 0,7%.

Castings were hand moulded. On moulding, the mould parting plane was flat and mould cavity was placed in the drag. Metal was fed to mould cavity through the two gating systems moulded on the longer casting sides (Fig. 3). They were designed according to general recommendations formulated in [4÷6].

Zirconia foam filters of 70×70×25 mm dimensions and porosity of 10, 15 and 30 ppi made by FerroTerm Sp. z o. o. [6] were placed directly under the down-gate (Figs. 3 and 4).

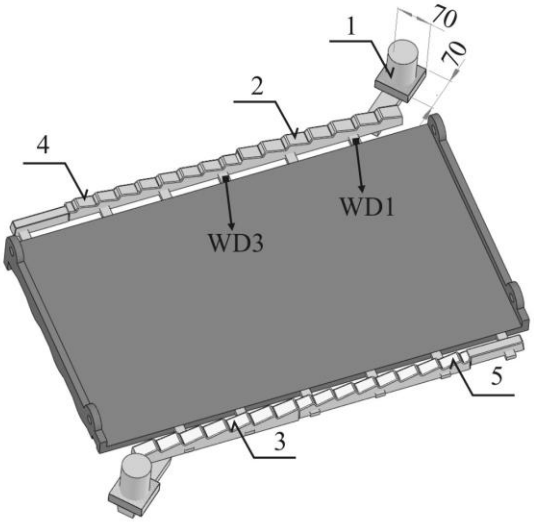

Fig. 3. Schematic representation of the technology of making cast hearth plates of 730×600 mm dimensions [7]; explanation of symbols in the text

Fig. 4. Filter location in the gating system [7]

2.2. Computer simulation of mould cavity filling

The use of filters in the manufacturing process of pilot castings was preceded by computer simulation done on a MAGMAsoft® programme [7]. The distribution of metal flow velocities and directions was examined in mould having a gating system with the built-in filter and without.

Examples of simulation results obtained for the casting technology as drawn in Figure 3 are shown in Figures 5 and 6.

With filter introduced to the gating system, the time of pouring was prolonged from 30 to about 35 seconds (Fig. 5a). The longer pouring time did not make alloy solidify during pouring into mould cavity. The metal front was overcooled, but its temperature did not fall below the point of liquidus. The accepted pouring temperature was 1580°C.

It seems that, flowing into the mould cavity through successive ingates, the metal streams were mildly touching the upraising metal mirror. No rapid mixing or turbulency has occurred.

The results of the simulation presented in Figure 5b show the time of the first contact between the metal and mould wall on pouring. One can see that in the system without filter, metal reaches the upper part of mould cavity earlier.

Comparing the metal flow rates in selected ingates (ingates WD1 and WD3 in Fig. 3) it is easy to note that the differences between the system with filter and without are relatively small (Fig. 6). Passing through the gating system with filter, the metal flow rate is only slightly lower and yet the difference is clearly visible. At the same time, in these ingates, the amplitude of changes in the flow rate is less sharp in the system with filter. In ingate WD3, the presence of filter had a very beneficial effect on the metal flow, since chocking at the 3rd second of pouring was effectively eliminated (Fig. 6b). Similarly, between the 3rd and 8th second of pouring, the flow rate was not changing so rapidly in the system with filter, as it happened in its non-filter counterpart.

The lower metal flow rate in ingates is caused by the lower flow rate in a cross-gate. It should have a very positive effect, enhancing the possibility of trapping pollutants and slag in a stepped ingate. The lower flow rate makes no disturbances, and hence does not cause mixing of metal which might draw slag into the mould cavity.

An analysis similar as the one described above was also made for the system in which the mould was inclined at an angle of 5^{o} [7].

2.3. Evaluation of casting surface quality

Using metal filtering system, a significant improvement in surface quality of castings was obtained. The evaluation was done through a comparison of the fraction of the area occupied by defects (P_W) in castings made with filter and without. The results of the comparison made for the ten cast plates with dimensions of 730×600 mm are shown in Table 1. A differentiation was made between the top (P_S) and bottom (P_R) casting surface in the “ready-for-pouring” position.

From the analysis shown in Table 1 it follows that introducing filter to a gating system has considerably increased the casting surface free from defects, mainly in the top (P_S) part (Tab. 1).

Before the use of filters, about 60% of castings were repaired. After modifications introduced to the technological process, the value of this index dropped to 10÷20%; the size of the defective surfaces was reduced quite radically, i.e. by approximately 90%.

2.4. Non-metallic inclusions in the gating system

Samples for evaluation of the content, shape and size of non-metallic inclusions were taken from the gating systems. The places where samples were taken are shown in Figure 3: 1 – in front of the filter, 2 and 3 – at a distance of about 160 mm from the filter, 4 and 5 - at a distance of about 540 mm from the filter.

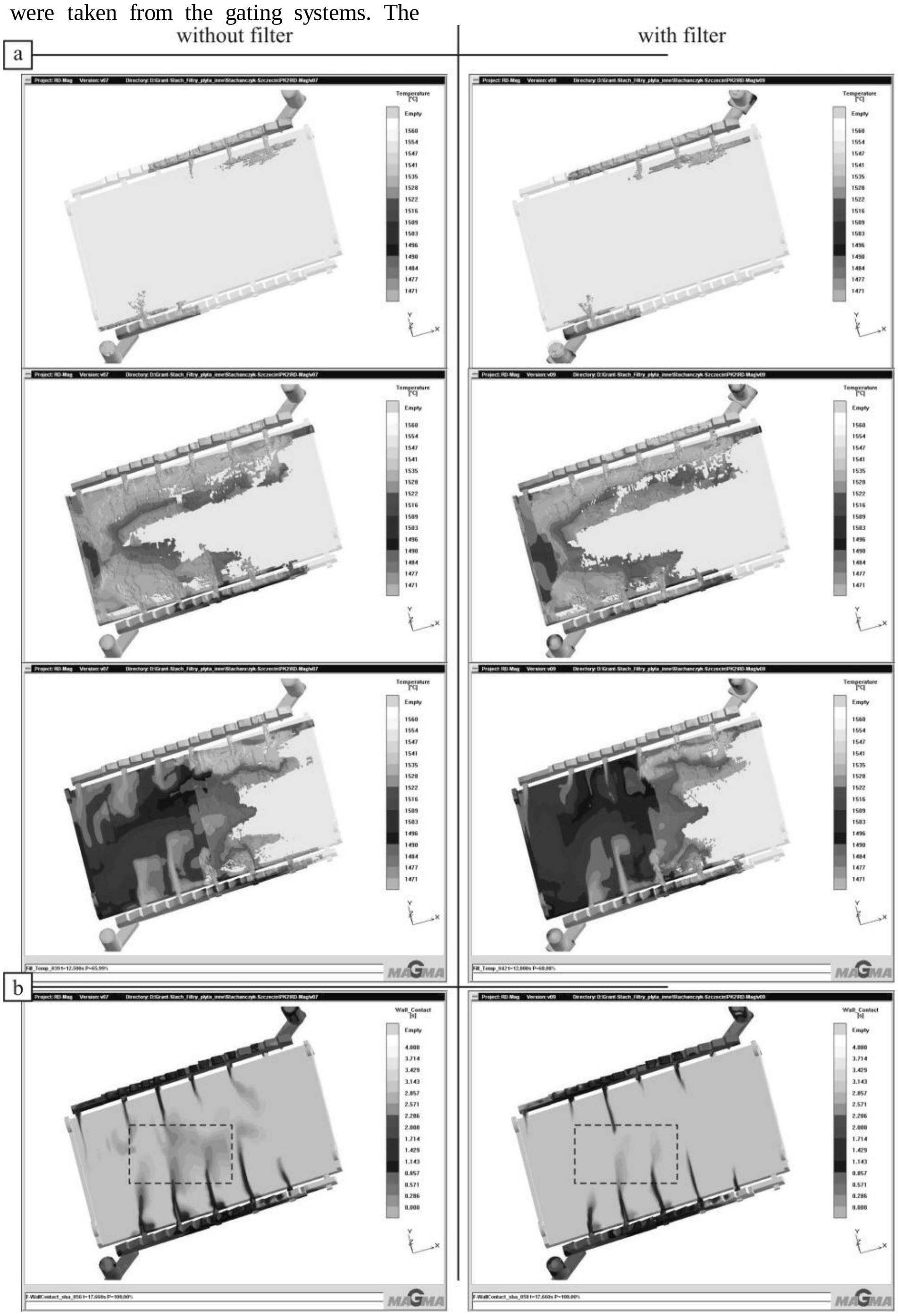

Fig. 5. The results of computer simulation of the mould cavity filling process when casting a hearth plate of 730×600 mm dimensions using the gating system without and with a 10 ppi filter [7]: a) temperature distribution on pouring, b) time necessary for molten metal to reach the top mould cavity; pouring temperature 1580ºC, time of mould cavity filling through the gating system without filter − 30 seconds, and with filter − 35 seconds

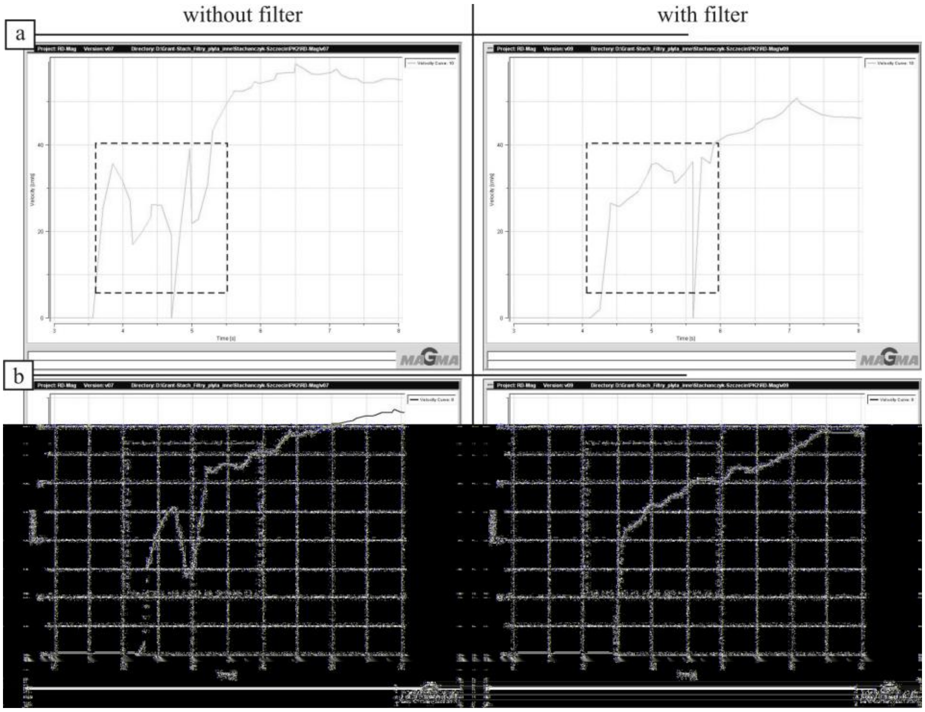

Fig. 6. The results of computer simulation of the mould cavity filling process when casting a hearth plate of 730×600 mm dimensions using the gating system without and with a 10 ppi filter [7]:
a) metal flow rate distribution in ingate WD3 (Fig. 3) within the time interval from the 4th to 15th second of pouring,
b) metal flow rate distribution in ingate WD1 (Fig. 3) within the time interval from the 1st to 6th second of pouring

Table 1.
Percent fraction of the flat casting surface occupied by defects; explanation of symbols in the text

	P_W, %			
	without filter		with filter	
	P_R	P_S	P_R	P_S
	0,14	2,15	1,03	1,14
	1,96	6,41	0,25	0,55
	0,45	31,51	0,32	0,27
	2,88	8,01	0,00	0,05
	3,15	20,39	0,07	0,68
	1,05	3,26	0,02	0,32
	10,41	12,51	0,43	1,04
	0,75	3,20	0,27	1,74
	0,27	13,40	0,18	2,24
	3,84	3,33	0,91	2,40
mean	**2,49**	**10,42**	**0,35**	**1,04**

The measurements were taken on unetched metallographic sections according to ASTME 124503 using a Metaplan 2 microscope and a Quantimet 570 Color image analyser. The mean values were calculated from 100 measurement fields for: content (A), perimeter (L_A) and number (N_A) of inclusions (Tab. 2). Examples of images of the inclusions visible on unetched metallographic sections are shown in Figures 7 and 8.

Table 2.
Quantitative evaluation of non-metallic inclusions – mean values; explanation of symbols in the text

	A, %	L_A, mm/mm^2	N_A, 1/mm^2
1.	0,320	6,135	1047
2.	0,165	1,977	229
3.	0,224	3,776	616
4.	0,214	2,866	461
5.	0,276	4,692	945

The effectiveness of filtration was evaluated from the change in oxygen content (this relates to non-metallic inclusions of oxides) along the length of the gating system according to the following equation:

$$\eta_0 = (O_p - O_f)/O_p \times 100 \quad (1)$$

where: η_0 – filtration degree [%], O_p – oxygen content in cast steel in front of the filter [ppm], O_f – oxygen content in cast steel behind the filter [ppm].

The content of oxygen was determined on a Leco Corp. TH336 analyser, making analysis at selected points of the gating system used for pouring of hearth plates. During examinations, the type of the filter was changed. The results of the measurements are compared in Table 3 (the N_2 content was measured automatically together with the O_2 content).

Table 3.
Mean content of oxygen and nitrogen in G-X40CrNiSi27−4 cast steel vs filter type; designations 1 and 2 as in Fig. 3

	O_2, ppm	η_0	N_2, ppm
1.	27,4	—	164
2. Filter 10ppi	13,5	50,7	130
2. Filter 20ppi	8,3	69,7	130
2. Filter 30ppi	7,4	73,0	127

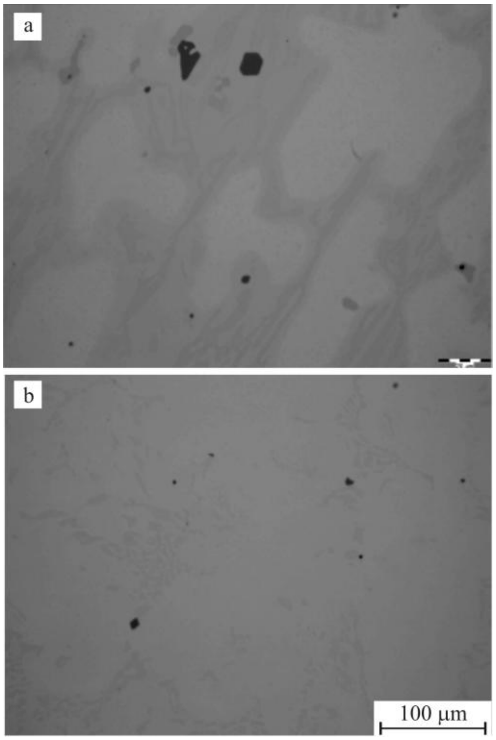

Fig. 7. Non-metallic inclusions in G-X40CrNiSi27−4 cast steel: a) in front of the filter, b) behind the filter; unetched state

3. Conclusions

The results of the study clearly show that the use of filters has improved the quality of the hearth plates cast from the heat-resistant G-X40CrNiSi27-4 cast steel.

The changes introduced to the manufacturing process reduced the severity of surface defects in raw cast hearth plates at least eight times (Tab. 1). As a result of the conducted tests and experiments, a significant reduction in the casting finishing operations was also achieved.

The evaluation of the filter operating effectiveness leads to the following statements:

— due to filtration the content of inclusions (their total area, number and perimeter) has decreased quite significantly (Tab. 2),
— on the filter are deposited mainly the inclusions of a size larger than 30 μm^2 (Fig. 7),
— the content of inclusions increases with increasing distance from the filter (Tab. 2), which confirms the results obtained in [8],
— the use of filters of higher porosity improves the filtration effect (Tab. 3),
— no reactions including low melting point phases take place between the flowing alloy and the material of the filter (Fig. 8).

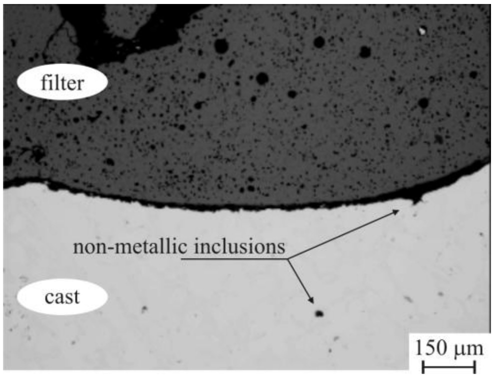

Fig. 8. Microstructure of GX40CrNiSi27-4 cast steel at the filter/metal interface; metallographic section; unetched

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