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Optimization of Side Feeders Systems by Means of Simulation of Solidification

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Abstract

Simulation software can be used not only for checking the correctness of a particular design but also for finding rules which could be used in majority of future designs. In the present work the recommendations for optimal distance between a side feeder and a casting wall were formulated. The shrinkage problems with application of side feeders may arise from overheating of the moulding sand layer between casting wall and the feeder in case the neck is too short as well as formation of a hot spot at the junction of the neck and the casting. A large number of simulations using commercial software were carried out, in which the main independent variables were: the feeder's neck length, type and geometry of the feeder, as well as geometry and material of the casting. It was found that the shrinkage defects do not appear for tubular castings, whereas for flat walled castings the neck length and the feeders' geometry are important parameters to be set properly in order to avoid the shrinkage defects. The rules for optimal lengths were found using the Rough Sets Theory approach, separately for traditional and exothermic feeders.

Keywords: Solidification process, Castings defects, Side feeders, Simulation, Design rules

1. Introduction

Numerical modeling and simulation software can be used not only for checking the correctness of a particular design but also for finding rules which could be used in majority of future designs [1]. One of the problems encountered by foundrymen is formation of shrinkage defects in castings in the regions of side feeders. The defects may arise due to overheating of the moulding sand layer between the casting wall and the feeder in case the neck is too short as well as a result of formation of a hot spot at the junction of the neck and the casting. Available handbooks and other published sources, based mainly on the industrial experience (e.g. [2-4]), do not provide precise hints and recommendations in this matter.

In the present work a number of simulations using commercial software were carried out, according the plan presented in the next section. Based on the obtained results, the rules for optimum lengths of the side feeders' necks and the feeders' geometries were formulated.

2. Methodology

2.1. Casting – feeder system details and plan of simulations

The input variables covered by the simulations were those having the greatest possible influence on the shrinkage defects formation, i.e. the feeder's neck length, type and geometry of the feeder, as well as geometry and material of the castings.

Two casting shapes were assumed: plate and tube, as shown in Fig. 1. The feeders were typical bind feeders with spherical top surfaces. All the dimensions are listed in Table 1.

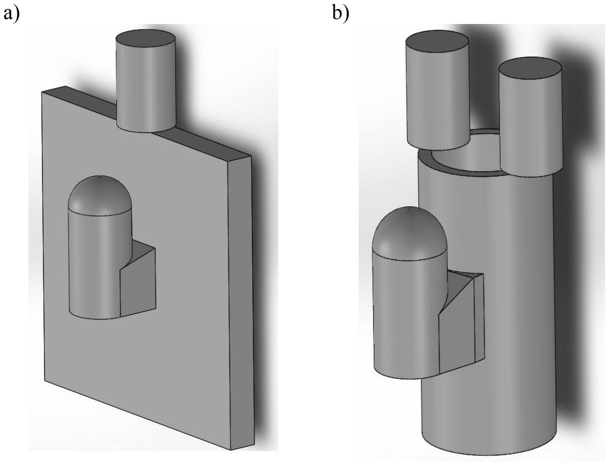

Fig. 1. Geometries of test castings with risers used for optimization of the neck's lengths

Table 1.
Dimensions of castings, feeders and necks used in simulations

Casting shape	Casting wall thickness range	Casting wall thickness, cm	Feeder h/D (height)	Neck length (fraction of feeder's diameter)
Plate	small	3		
		5		
	medium	7	1 (low)	0.25
		10		0.5
	large	20	1.5	0.75
Tube	small	2	(medium)	1
	medium	6		1.5
		10		2
	large	14	2 (high)	
		20		

Two types of feeders were taken into account: traditional and exothermic. The assumed thickness of the exothermic (blind) sleeves was 13 mm for all feeders. The feeders' dimensions were calculated assuming the feeder's modulus to casting's modulus ratio equal 1.2. All the feeders' necks had square cross-sections at the junction with the casting and rectangular cross section with the horizontal side measurement equal to the diameter of the feeder.

Two types of cast alloys were examined: low carbon steel and a grey cast iron. All the materials properties as well as the initial (pouring) temperatures were assumed from the original software database. In order to calculate the correct dimensions of the exothermic feeders, it was necessary to calculate the thermal modulus of the feeder with the sleeve made of the material included in the software database. The required coefficient of the modulus enlargement due to coating the feeder with an exothermic sleeve (also known as feeder's efficiency) was found from the simulation of the system shown in Fig. 2.

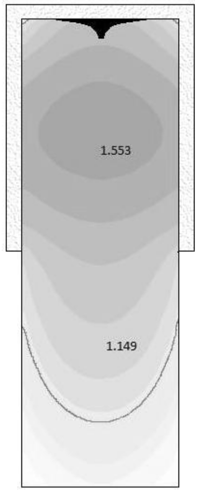

Fig. 2. Simulation results of the cylindrical casting used for calculation of the exothermic sleeves efficiency assumed in NovaCast software; the numbers indicate thermal moduli at the geometry centres of the both halves of the casting: upper (with sleeve) and lower (without sleeve)

Two types of moulding sand were applied: clay bonded green sand and furan sand. Most of the simulations were made assuming green sand as the first round of the simulations showed negligible differences in the shrinkage defects distributions for these two moulding materials.

The software used in the simulations was NovaFlow&Solid package (research and educational version 2.92r15), by NovaCast Systems AB, utilizing the Finite Difference Method. The computational fundamentals can be found in the electronic manual available from the software provider.

2.2. Generation of design rules

Due to a large number of simulation results it was advisable to apply an objective methodology for finding the practical designing rules. The most popular learning systems capable of extracting logic rules from examples are probably the Classification Trees (CTs). However, the experiences of some authors' show that the classification systems obtained from the Rough Sets Theory (RST) exhibit significant advantages over CTs [5-9] and seem to be their newer alternative in many process industry applications.

Extraction of rules from RST requires that not only an output variable, but also all input variables (called attributes), are of discrete type. Each discernible learning example (data record) can be basically a rule [8, 9]. Thus obtained set of rules can be usually reduced and the rules can be simplified (i.e. their conditional part can be shortened). The rules can be evaluated, first of all from the standpoint of uniqueness of the classification. This is expressed by their confidence, defined as ratio of the number of examples with this same combination of attributes values and class variable as in the rule, to the number of examples with this combination of attributes values (regardless the output class). If it is not possible to obtain rules of 100% confidence, then some not fully unique rules are utilized. Another parameter used for evaluation of the rules is the number (or fraction) of examples compatible with a rule, called rule's support. In the present work generation of the rules from the RST was carried out with the use of software developed at Warsaw University of Technology [9].

Several data sets were prepared, independently for each combination of cast alloys (steel and cast iron), feeders (traditional and exothermic) as well as casting geometry (plate and tube). The input variable "casting wall thickness" was expressed in the verbal form (with the values 'small', 'medium' and 'large') as shown in Table 1. The remaining numerical values, i.e. the feeder h/D ratio and the neck length (expressed as a fraction of feeder's diameter) were kept in their original form, but were treated as text-type discrete values.

3. Results

3.1. Typical defects obtained from simulations

According to the plan described in Section 2.1, over 170 simulations of solidification of different casting – feeder systems were carried out. All results presented below are in the form of screenshots obtained from the NovaFlow&Solid software, displaying density distributions of the solidified metal at the symmetry cross-sections of the casting – side feeder systems. The general observations are given below.

The shrinkage defects may be substantially different for cast iron and steel castings of the same geometry. An illustrative example is shown in Fig. 3.

a) b)

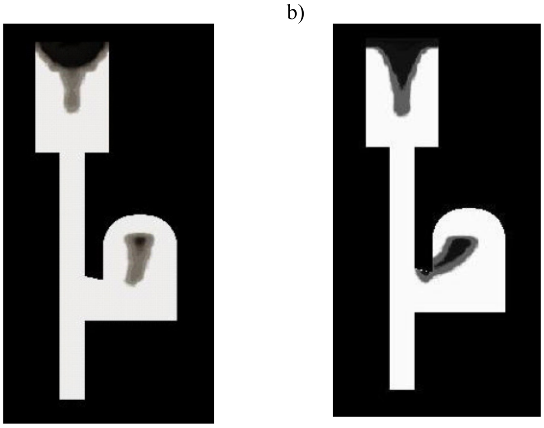

Fig. 3. Exemplary distributions of shrinkage defects obtained for the same casting geometries (traditional feeders): a – steel, b – grey cast iron

As mentioned in Section 2.1, the shrinkage defects were practically identical for the both moulding materials, i.e. green sand and furan sand. Exemplary density distributions are shown in Fig. 4. This result was certainly not obvious as the thermal properties of these two moulding materials are different. The results of simulations obtained for furan sand were excluded from the sets used for the rule extraction in order to avoid doubling the records obtained for the same geometries and other parameters.

a) b)

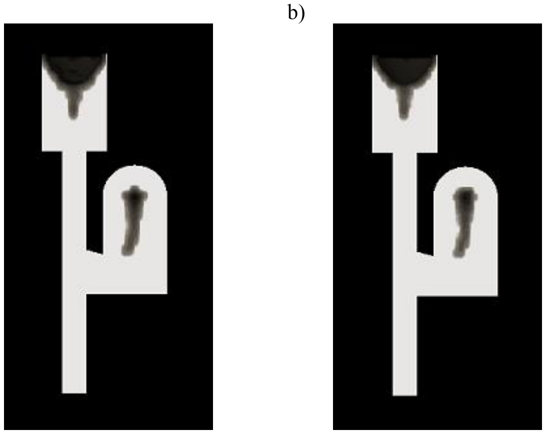

Fig. 4. Exemplary distributions of shrinkage defects for steel castings with traditional feeders obtained in: a – green sand mould, b – furan sand mould

Two types of shrinkage defects were observed, as illustrated in Fig. 5. One was due to formation of a hot spot at the junction of the neck and the casting (Fig. 5a). The other was triggered off by overheating of the sand layer between the casting wall and the feeder (Fig. 5b).

a) b)

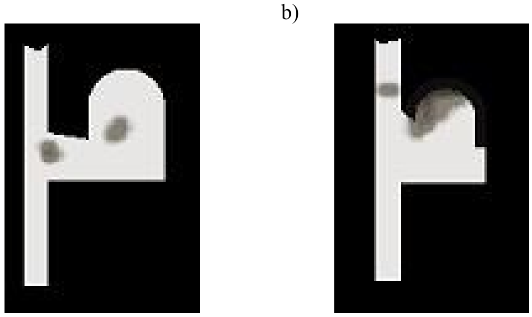

Fig. 5. Two typical shrinkage defects obtained in simulations (grey cast iron); a – due to local hot spot formed at the connection of too long neck, traditional feeder, b – due to overheating of the sand layer by the exothermic feeder

It was observed that the distance between the feeder and the casting wall, i.e. the length of the neck, has a high influence not only on appearance of the second type of the shrinkage defects, i.e. related to overheating of the casting, but also on formation of hot spots at the feeder – casting junctions. Typical density distributions are presented in Fig. 6. These hot spots are likely to appear in case of long necks, including much longer ones, not shown in Fig. 6. This result was not obvious and may be particularly important for cast iron castings where long necks are sometimes recommended [4]. However, that kind of feeding system design is connected with the approach based on compensation of the liquid contraction only, requiring small feeders. The conclusion is that the long necks should certainly not be applied for conventional feeding systems.

Fig. 6. Influence of the neck length on appearance of shrinkage defects at the neck junction (traditional feeders, cast iron castings)

Another important observation was that in all simulations carried out for the tube-shaped castings no shrinkage defects related to the side feeders were observed. An illustrative example is shown in. Fig. 7.

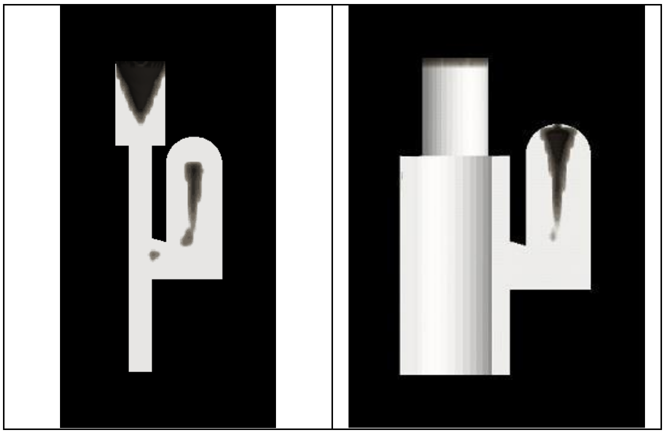

Fig. 7. Comparison of shrinkage defects at the neck junction in plate-shaped and tube-shaped castings of similar sizes (traditional feeders, cast iron castings)

The possible reason of this is that the convex casting surface is generally 'more distant' from the neck and the feeder and thus is less prone to create the hot spots. Consequently, the design rules were elaborated for the plate-shaped castings only.

3.2. Design rules

As a result of the simulation plan and the observations discussed in Section 3.1, the design rules were extracted from the four training data sets (combinations of two types of alloys and two types of feeders). In Tables 2, 3, 4 and 5 only the rules for sound castings are presented, although the rules for defective castings are also extracted by the RST based software. An empty cell in the conditional part of the rule means that the given condition does not appear in the rule, i.e. this design parameter can be set arbitrarily.

In all 4 cases there are some rules of 100% confidence and some of them also have relatively high fractions of supporting records. This kind of rules can be treated as the most reliable ones and can be successfully utilized in the designing practice.

A closer analysis leads to the following conclusions and further selection of the rules which would be most suitable for design purposes.

For steel castings with conventional feeders (see Table 2) four rules with 100% confidence were obtained. The first one seems to be the most suitable for design practice because it is very simple: "*if a low feeder is applied (irrespective of the casting wall thickness and the neck's length), then the casting will be sound*". In general, the shorter rules, i.e. containing small numbers of conditions are more versatile and usually easier in practical applications. The selected rule has also one of the largest numbers of supporting records.

Table 2.
Rules obtained from RST theory for plate-shaped steel castings with conventional side feeders; the rule marked in grey is selected as the most suitable for design purposes

Conditions for sound castings				
Casting wall thickness	Feeder height	Neck length (fraction of feeder's diameter)	**Rule confidence**	**Rule support**
	low		100%	24%
small		0.25D	100%	29%
	medium	0.25D	100%	24%
small	high		100%	10%
small			86%	29%
		0.25D	80%	57%
medium	medium		67%	10%
	medium		63%	24%

This case is also a good illustration of the advantages of the RST based rules extraction system over the commonly used CTs. In Fig. 8 the structure of the CT obtained from this same training data set is shown, using the commercial software Statistica v. 8. There are three rules for sound casting resulting from CT:

"*neck length is 0.25 and feeder height is low*"

"*neck length is 0.25 and feeder height is medium*"

"*neck length is 0.25 and feeder height is high and wall thickness is small*"

It can be seen that although the CT rules are similar to some of the RST rules, the most practical and certain rule resulting from RST mentioned above cannot be obtained from the CT. The reason is that the first splitting variable, which is the neck length, must appear in all rules.

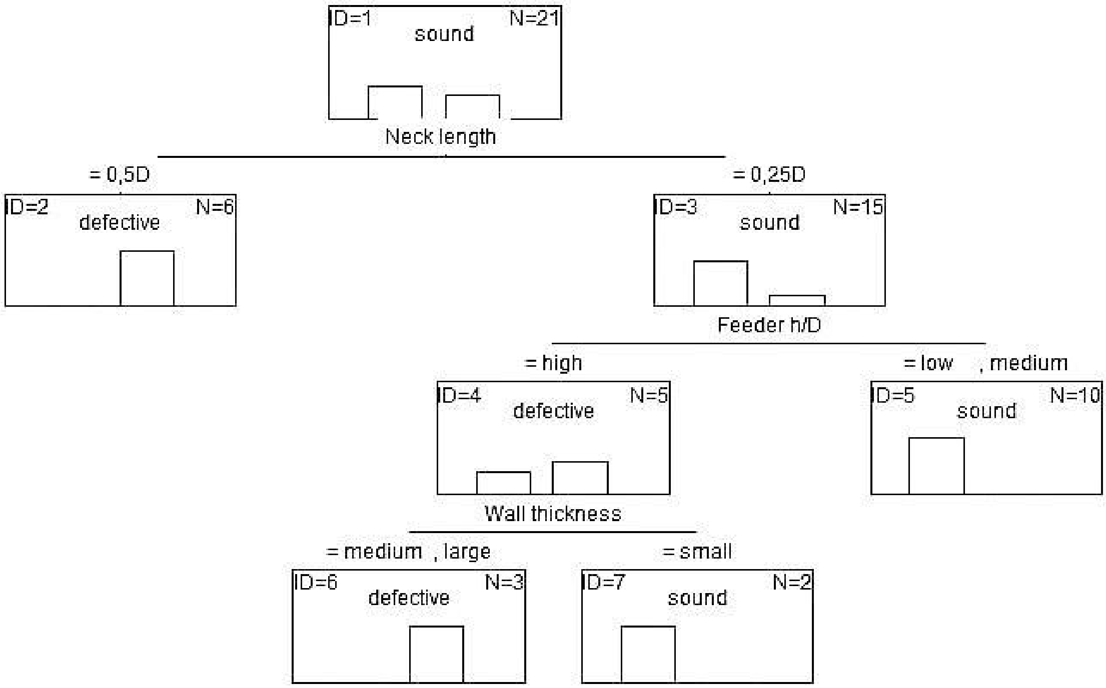

Fig. 8. Classification tree for steel plate-shaped castings with conventional side feeders; two classification results (leaves) with 'sound' class can be seen in the bottom right part of the graph

For steel castings with exothermic feeders (see Table 3) there are 3 rules with 100% confidence. However, in this case selecting an appropriate rule may be difficult. All of these rules have relatively low support and all have 2 conditions which must be satisfied. The most difficult situation is with thin-walled castings, because there is no rule of 100% confidence for such castings. It is necessary to follow one of the less certain rules, with 80% and 71% confidences. Ultimately, the practical recommendations for steel castings with exothermic feeders may be formulated as follows. For medium and thick walled castings low feeders should be applied, and the neck length is not important. For thick walled castings any feeder geometry is acceptable, providing the neck length is 0.25D. For thin walled castings the feeders should certainly be low and it is better to keep the neck length equal 0.25D.

For grey iron castings with conventional feeders (see Table 4) five rules with 100% confidence are available. The most useful seems to be the second one, which says that using high feeders and the necks lengths equal 0.25D ensures making sound castings, irrespective of their wall thickness. Also, for medium thickness of the casting walls any feeder can be applied, combined with the same neck length.

For grey iron castings with exothermic feeders (see Table 5) there are 4 rules with 100% confidence. All of them contain all the three conditions. Like in the case of steel castings (Table 3), none of these rules applies to thin walled castings. This observation indicates, that exothermic side feeders are rather difficult in application to thin walled castings and should possibly avoided. On the other hand, increasing the casting yield with the utilization of exothermic sleeves may be not so profitable for such castings. However, if one would like to use them, the high feeders should be avoided and the neck length must be about 0.25D (rules of 80% confidence).

Table 3.
Rules obtained from RST theory for steel plate-shaped castings with exothermic side feeders; the rules marked in grey are selected as the most suitable for design purposes

Conditions for sound castings				
Casting wall thickness	Feeder height	Neck length (fraction of feeder's diameter)	**Rule confidence**	**Rule support**
large		0.25D	100%	12%
medium	low		100%	8%
large	low		100%	4%
	low	0.25D	80%	15%
	low		71%	19%
medium		0.25D	67%	15%
large			60%	12%
		0.25D	53%	31%
medium			50%	15%
small	high	0.5D	50%	4%

Table 4.
Rules obtained from RST theory for grey iron plate-shaped castings with traditional side feeders; the rule marked in grey is selected as the most suitable for design purposes

Conditions for sound castings				
Casting wall thickness	Feeder height	Neck length (fraction of feeder's diameter)	**Rule confidence**	**Rule support**
medium		0.25D	100%	24%
	high	0.25D	100%	20%
medium	low		100%	8%
medium	medium		100%	8%
large	low		100%	4%
	low	0.25D	80%	16%
medium			75%	24%
		0.25D	73%	44%
	low		57%	16%
	high		50%	20%

Table 5.
Rules obtained from RST theory for grey iron plate-shaped castings with exothermic side feeders; the rules marked in grey are selected as the most suitable for design purposes

Conditions for sound castings				
Casting wall thickness	Feeder height	Neck length (fraction of feeder's diameter)	**Rule confidence**	**Rule support**
medium	low	0.25D	100%	7%
medium	medium	0.25D	100%	7%
large	low	0.25D	100%	3%
large	medium	0.25D	100%	3%
	low	0.25D	80%	13%
	medium	0.25D	80%	13%
medium	low		75%	10%
medium		0.25D	67%	13%
large		0.25D	67%	7%
	low		60%	20%
		0.25D	53%	27%
	medium		50%	17%
small		0.5D	50%	10%

4. Conclusions

The benefits resulting from the present work are threefold. First, the design rules for side feeders are obtained, filling the gap in the currently available engineering literature.

Second, the usefulness of the automated rule extraction systems based on RST is confirmed. This approach offers clear and versatile usage of available data, including those obtained from planned experiments (numerical or real) as well as obtained form normal production.

Third, an important observation, concerning usage of the exothermic sleeves was made: the feeder – neck system seems to be more prone to create undesired hot spots and related shrinkage defects compared to traditional feeders. In particular, exothermic side feeders may be difficult in application to thin walled castings and should be applied with care.

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