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PRESIDENT MESSAGE

Pakistan Foundry Association is pleased to announce the 8th International Foundry Congress & Exhibition (IFCE) to be held on 14th-15th Feb, 2023 at Pearl Continental Hotel, Lahore-Pakistan. The theme of the conference is "Foundry Technology for Cost Reduction".

IFCE-2023 will connect exhibitors to their potential buyers. We are making special efforts to invite buyers of castings and casted components from all major industrial sectors like Cement, Sugar, Heavy Engineering Sector, Chemical, Automobiles, Tractors, and Power. The 8th IFCE will provide an opportunity to large, medium, and small foundries, machinery manufacturers, foundry material suppliers and service providers to showcase their products and services to visitors and potential buyers.

Technical Sessions by global experts introducing new technologies, processes, skills and will guide foundries in reducing their manufacturing related technical issues. IFCE holds a legacy of success, with exhibitors, buyers and General & Industrial participants.

I am also glad to see that Pakistan Foundry Association (PFA) is aggressively moving towards its objective of upgrading & optimizing Foundry processes in small and medium foundries. PFA has successfully done hand-holding of more than 60 foundries in use of Alphaset No-bake process. Many foundries now understand how Alphaset molding technology can control Defects, Weight and quality of castings. Membership circle of PFA is now expanding.

At PFA, with the support of our friends world wide, we will continue our journey of upgrading & optimizing foundry processes, enabling SME sector to produce world class castings for global markets.

I would like to invite all PFA members, international exhibitors, technical decision makers from local industry, machinery manufacturers, foundry material suppliers, service providers and investors to join us at IFCE-2023 to benefit from this mega opportunity and make it a success.

Sikandar Mustafa Khan
President-PFA

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5 Types of Metal Casting Defects and Causes

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As the name implies, casting defects refer to irregularities that appear in the metal casting process. In this section, we will discuss different sand casting defects and causes. Only in this way can you prevent metal casting defects and avoid defective products. This guide will start with 5 types of foundry casting defects and causes to help you identify, repair, and avoid casting problems.

Metal casting defects and causes

Common defects in metal castings are divided into five categories: holes, cracks, surface defects, unqualified shapes and sizes and weights, and unqualified components and structures and properties. (Note: Mainly introduce the steel casting defects that are easy to cause cracks)

1. Perforated casting defects

Hole steel casting defects include pores, shrinkage holes, shrinkage porosity, slag holes, trachoma, and iron beans.

Stoma

Also known as gas eyes, bubbles, holes casting defects caused by gas. The characteristics of casting pores are: generally round or irregular holes, the inner surface of the holes is smooth, and the color is white or with a layer of old dark color.

The causes of casting defects are: the furnace material is wet or corroded; the surface is not clean, the steam in the furnace gas and other gases; the furnace body and the ladle are not dried after repair; the gas in the cavity and the improper pouring system; the gas is involved in the casting, Poor permeability of mold or mud core, etc.

Shrinkage cavity

These are hole casting defects caused by shrinkage. The characteristics of shrinkage cavity are an irregular shape, roughness in the hole, and coarse crystal grains.

The reason for casting defects is metal shrinks during liquid and solidification. The main points are as follows: unreasonable casting structure design; improper casting system; the size, quantity, and location of the chilled iron do not match the reality; the chemical composition of the molten iron does not meet the requirements, such as excessive phosphorus content. Pouring temperature is too high, running speed is too fast, etc.

Shrinkage

Also called looseness, pinhole honeycomb, and small and many holes casting defects caused by shrinkage resistance. Shrinkage porosity is characterized by:

• Tiny and disjointed pores.
• Coarse crystal grains with obvious mesh holes between the crystal grains.
• Water seepage during the hydraulic test.

Scum eye

Slag hole casting defects are also caused by slag inclusion, slag bag, dirty eye, low molten iron temperature, and improper casting of slag. The characteristics of the slag hole are: the shape of the hole is irregular and not smooth; the whole or part of the hole is filled with slag.

The reasons for casting defects are: insufficient purity of the molten iron; poor slag removal and poor slag retention during pouring; poor slag retention by the gating system, and the gate is not full or cut during pouring.

Trachoma

Trachoma is trachoma casting defects with sand in between. The characteristics of trachoma are: the holes are irregular, and the holes are filled with molding sand or core sand.

The reasons for casting defects are: The molding sand is damaged and peeled off when the box is closed. The loose sand or sand blocks in the cavity are not cleaned. The molding sand has poor compactness, and the core is broken during pouring; improper gating system design, poor core surface coating, etc.

Iron beans

Iron beans are holes that hold iron beads. Also known as an iron bead, bean eye, iron bean trachoma, etc. The characteristics of iron beans are: the holes are relatively regular, and the holes contain tiny metal beads. Such casting defects often occur in iron castings.

2. Cracked casting defects

Cracking steel casting defects include hot tear defect, warm cracking, and cold shut defect.

Hot crack(hot tear defect)

Thermal cracking casting defects occur at a higher temperature and near the solidification temperature. The characteristics of thermal cracking are penetrating or non-penetrating cracks on the casting; it is curved, and the surface of the crack is oxidized.

The reasons for metal casting defects are excessive sulfur content or excessive impurities in the iron; poor retreat performance of the sand casting mold; improper pouring temperature control; the severe transition of the casting wall thickness transition; gate, cold iron, shrinkage ribs, vent holes Improper size and location, etc.

Warm crack

Thermal cracking is also called heat treatment cracking. These metal casting defects are caused by improper cutting, welding, or heat treatment. The characteristics of warm cracking are: there are penetrating or non-penetrating cracks on the casting; the metal surface of the crack is oxidized.

Cold crack(cold shut defect)

Cold crackings are crack casting defects produced by castings at lower temperatures. The characteristics of cold cracking are penetrating or non-penetrating cracks on the casting; it is linear, and the surface of the crack is not oxidized.

The reasons for casting defects (casting defects with images) are:

• Unreasonable casting structure, uneven thickness.
• Poor retreat performance of sand casting mold or mud core.
• Inconsistent cooling of various parts of casting, the high-stress tendency of the alloy itself.

3. Surface casting defects

Surface steel casting defects include sand sticking, scarring, sand inclusion, and cold isolation.

Cold isolation

We mainly introduce the cold partition that can cause casting cracks. The cold compartment is also called anti-fire, receiving fire, and so on.

The characteristics of the cold partition are: there are irregular and obvious sinking linear lines on the surface of the workpiece (there are two kinds of penetrating and non-penetrating).

Its shape is small, long, and narrow, and it has a development trend under external force. Judging from the characteristics of the cold barrier, it is easy to cause damage to the mother's body. Cracks casting defects caused by the hard barrier will not appear immediately. When it is in use, fatigue cracks are produced under the action of bearing and impact.

Reason for casting defects：

Multiple ladles and multiple points are poured simultaneously so that the two metal streams are connected. But incomplete fusion and no inclusions exist between, so the two-layer metal bond is fragile; the pouring temperature is too low, the pouring speed is too slow, and the pouring time is too long. The alloy has poor fluidity, too low carbon and silicon, and high sulfur content. Or multiple ladles are poured sequentially, and the cut-off time of the front and rear ladle is too long; the casting section is thin and long, the molten iron flow is unfavorable, the casting flow is interrupted, the sand casting mold runs out, the one-time molten iron is insufficient, and the supplementary pouring is not timely.

4. Metal casting defects of unqualified size, shape, and weight

Metal casting defects of unqualified size, shape, and weight castings include: fleshy, insufficient pouring, falling sand, box lifting, eccentricity, deformation, wrong box, damage, shape, size and weight inconsistency, etc.

5. Foundry casting defects with unqualified composition and performance

Steel casting defects of unqualified composition and performance include unqualified chemical composition; unqualified metallography; unqualified segregation, excessive hardness, and unqualified physical and mechanical properties.

Treatment of Steel Casting Defects

The treatment of steel casting defects is more critical, especially when dealing with cracks. Failure to pay attention to any link in the process will cause new cracks. Therefore, we must pay attention to the processing details, strictly implement the process, and ensure quality.

1. The principle of repairing defects in foundry steel castings:

The repair of casting defects must be carried out without affecting the quality of the product. Repair should be carried out in accordance with relevant standards and relevant technical regulations. For example, whether the existing casting defects are allowed to be repaired and the relevant technical requirements for improving.

2. Treatment method of steel casting cracks

Welding repair is one of the primary production processes of steel castings. Almost all casting defects on steel castings can be repaired by welding. Arc welding is widely used.

Main points of welding repair: In order to ensure the quality of welding repair, we should carefully clean up the sticky sand, oxide scale, inclusions, etc., of the casting defects; open the groove; do pre-weld preheating and post-weld heat treatment according to the weldability of the steel.

(1) Stop cracks and eliminate cracks

The cracks can be eliminated by arc gouging, angular grinding wheel grinding, and cold elimination method of windmilling. It is suggested that the crack elimination of essential parts should be eliminated by cold as much as possible to reduce heating as much as possible. Superficial cracks may not be used as crack arrest holes. The depth and width of the crack are relatively large, and the crack stop hole of 5-8mm must be prefabricated within 10mm of the end of the crack before treatment to prevent the crack from extending.

(2) Prefabricated groove and gap

When we deal with the cracks in the castings of factory repairs, axle box tie rod seats, side bearings, etc., the welds are required to be welded through. Generally, a 60-degree V-shaped groove is used, with a clearance of 2mm. For essential parts, T-shaped joints, or corner joints with serious cracks, it is recommended to open a 30-degree V-shaped groove to the vertical plate to ensure the quality of the fusion.

(3) Preparation before welding

To deal with cracks, we recommend using alkaline electrodes to improve crack resistance and toughness. Before welding, it is required to preheat the electrode to 200-250⊠, and the operating temperature should not be lower than 150⊠. The ambient temperature is not lower than 5 degrees. It is required to grind the grinding wheel within 20mm of the groove surface and the welding surface. The grooved surface is not allowed to have more than 2mm grooves. The metal surface is free of oil stains, oxides, and rust. It is recommended to preheat the steel casting matrix before welding. It is best to use overall preheating. If overall preheating is not possible, partial preheating can be used. The range of local preheating is at least three times the width of the section thickness of the weld on both sides of the weld.

Welding process

Welding must be carried out by qualified personnel who have passed the flat welding test. When welding, a reasonable welding specification should be selected. When starting arc welding, prevent the arc from damaging the surface of the casting. It is forbidden to ignite the hook in the non-welded area. Welding parts should avoid artificial blowing and draughts. The butt weld cannot be filled too much at one time, and multi-layer welding shall be adopted, which shall not be less than three layers. The first layer of welding is welded with a smaller diameter electrode to prevent thermal cracks. After each layer is welded, the slag should be completely removed before soldering the next layer. During welding, the interlayer of the weld should be kept not lower than the preheating temperature. For welding with longer welds greater than 200mm, the segmented method shall be used. The arc starting and ending positions of each layer should be staggered by no less than 20mm. Try to avoid blind spots and terminal arc starting or ending.

3. Welding repair of cast iron parts

If the casting defects such as pores, sand holes, slag inclusions, cracks, and leakage on the iron castings do not exceed the allowable range of welding repairs, they can be repaired by welding. However, the welding performance of cast iron is poor. After welding, pores, deformation, easy to break, difficult to process, and other problems often appear. Therefore, you should be very cautious when welding and repairing cast iron.

(1) Welding repair method: The welding repair method of cast iron is usually classified according to the preheating temperature of the workpiece

(2) Cold welding is called cold welding if it is not preheated before welding or only preheated to below 250⊠; preheating to 250⊠450⊠ before welding is called semi-hot welding; preheating to 500⊠700⊠ before welding is called Hot welding.

Conclusion

Here we have presented the basics of porosity, shrinkage, mold materials, pouring metal, metallurgy, and casting shape defects. Specific examples of defects that can occur in castings are included. Now that you are more familiar with the types of failures that can occur in castings, are you ready to start purchasing? If so, you can check out our detailed information. Or, if you'd like to view additional industry guides, you can check out the Guides section of our website for actionable information to help you make better purchases.

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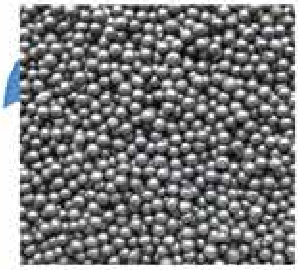




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Importance of Energy Management in Foundries

Seweryn Jarża *

Abstract

Pollution prevention is preferable to reliance on end-of-pipe pollution control. Since we look at the environment in the global sense, it is irrelevant that the emissions reductions occur at the electrical generating station rather than at the site of the efficiency improvements. In foundries as a part of an energy intensive industry, energy accounting is necessary to determine where and how energy is being consumed and how efficient is the energy management system. The main aim of energy management should define the areas of high energy use, energy waste and should point out areas in which energy saving can be accomplished. Energy management is very important as it deals with adjusting and optimizing energy, using systems and procedures so as to reduce energy requirements.

Keywords: emission, environment, pollution prevention, energy management

Introduction

Cleaner production encompasses production processes and management procedures that entail less use of resources than conventional technologies and also generate less waste and smaller amounts of toxic or other harmful substances. It emphasizes the human and organizational dimensions of environmental management, including good plant operation to avoid deliberate or accidental discharges. Cleaner production and pollution prevention reduce the quantities of waste and eliminate some pollutants, but treatment and disposal of remaining wastes are also required. Improved energy efficiency reduces greenhouse gas emissions in two ways:

- Energy efficiency measures for on-site combustion systems (e.g., furnaces, boilers, cupolas, heat-treating ovens) reduce emissions in direct proportion to the amount of not consumed fuel.

- Reductions in consumption of electricity lead to reductions in demand for electricity and, consequently, reductions in emissions from thermal electric power generating stations.

We have to remember that the key environmental issues included emissions to all environmental media; energy consumption has the first place but other environmental issues (such as consumption of raw materials, emission of noise, vibration, heat) and other factors can't be overlooked.

According to data of International Energy Agency world primary energy demand is expected to increase 1.5% per year between 2007 and 2030. Separately by source of energy world, electricity use is expected to growth at an annual rate of 2.5% to 2030 and oil demand by rate of 1%. More than 80% of this growth is related to the OECD (Organization for Economic Co-operation and Development) countries. Industry sector consumes produced electricity in the world with rate about 42.2%. Increase in use of energy and fuels have consequence of rising CO2 emission with the predictable growth rate of 1.5% over the mentioned period[1]6.
Energy intensive sectors like petrochemical sector, iron and steel sector and non-metallic mineral sector account approximately 50% of the total final energy use both in OECD and non-OECD countries (Fig.1).

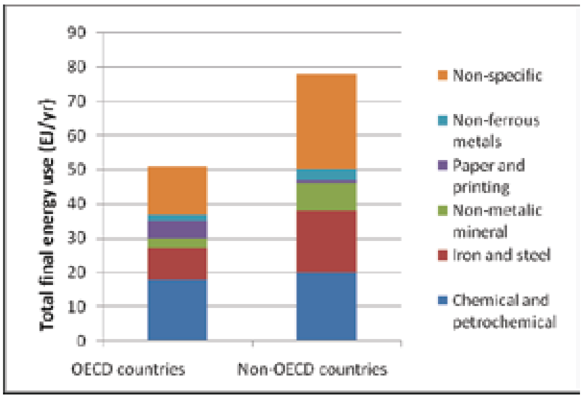

Figure 1. Breakdown of total final industrial energy use in OECD and non-OECD countries in 2007. Source: IEA, 2009a,b

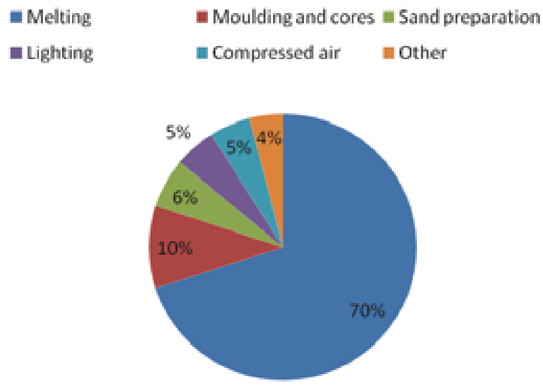

Figure 2. Typical distribution of energy consumption in foundries

As the foundry industry is an energy intensive industry, focusing on its energy use and ways to reduce and save the energy in this industry is considerable.

No.	Description	Energy Consumption
1	Specific Power Consumption norm in Induction furnace per ton of liquid metal	620 kWh/ton
2	Specific coke consumption norm in cupola per ton of liquid metal	135 Kg/ton

Table 1 Energy consumption in melting process [2][7].

Table 1 shows the specific energy consumption understood as the energy consumed per ton of liquid metal produced. BAT (best available techniques) are the most effective in achieving a high general level of protection to the environment as a whole and for melting process induction furnaces in place of cupola furnaces are preferred.

As it's easy remarkable on fig. 2, the other main processes in energy consumption are molding and cores preparation. These processes creates large quantities of pollution as well. So the conventional energy and material efficiency policy in foundries which yields about 1 % annual increase in resource efficiency will not be sufficient to meet necessary challenges.

Profile of foundry industry

Metal castings are the first step in the manufacturing chain and of most durable goods. Foundry operations have always been varied and complex, and they have become even more so. Castings of iron, steel, light metals (such as aluminum), and other metals (such as copper and zinc) are made in units that may be independent or part of a production line. The main production steps include:

- preparation of raw materials,
- metal melting,
- preparation of molds,
- casting
- finishing (which includes fettling and tumbling).

Presently an electric induction furnaces are used to melt iron and other metals. However, large component foundries and some small foundries melt iron in gas or coke-fired cupola furnaces and use induction furnaces for aluminum. Melting capacities of cupola furnaces generally range from 3–25 metric tons per hour (t/h). Induction furnaces are also used in zinc, copper, and brass foundries. Electric arc furnaces are usually used in stainless steel and sometimes in copper foundries. Complete mold is filled with molten metal, using ladles or other pouring devices. Large foundries often have pouring furnaces with automatically controlled pouring process. For hollow casting, the mold is fitted with a core. Finishing processes such as fettling involves the removal from the

[6] IEA (International Energy Agency), 2009 a, World energy outlook, executive summary. 2009, available on http://www.worldenergyoutlook.org/docs/weo2009/WEO2009_es_english.

[7] data according to Arasu M., Rogers JL "Energy consumption studies in cast iron foundries" Transactions of 57th Indian Foundry Congress, Kolkata, India, 2009

casting of the gating system, fins (burrs), and sometimes feeders. This is accomplished by cutting, blasting, grinding, and chiseling. Small items are usually ground by tumbling, carried out in a rotating or vibrating drum, usually with the addition of water, which may have surfactants added to it.

Emissions from the melting and treatment of molten metal, as well as from mold manufacture, shakeout, cleaning and after-treatment, is generally of greatest concern. To reduce the emissions and to keep the emissions as low as necessary it is indispensable to implement technical measures which gives an opportunity for creating the tasks and strategy. Integrated index of energy consumption per standard unit is one of the main measure. The rapid escalation of natural gas prices and the deregulation of the electricity market have spotlighted the need to address energy efficiency issues. . In Canadian grey iron foundries melting accounts for 66% of the energy consumption; in steel foundries it is 50%; and in brass and bronze foundries, the figure is 38%. As can be calculated, on average, the total energy content in iron castings is 50% higher, in steel castings 60% higher, and in brass and bronze castings 100% higher than the energy required to melt of the metals8. . This gives an idea of the current energy consumption of the foundries, which can be compared with standard norms and can be used to implement deviation control methods. This is also the challenge for exploration the various avenues for energy savings and cost control.

Energy management

Energy management is an ongoing concern in any foundry. Its success depends on a team effort starting with a firm commitment from the top executive and his or her management team. Since the primary business goal is financial savings, managers must understand the principle of economics and run their department as if it were their own business. Currently, there appears to be a lack of reliable information on the total production and benchmarking data of Polish foundries; no single organization is known to keep track of all of it. Publishing of consolidated reports by Foundry Research Institute in Cracow relating to cast iron industry was initiated in 2010 but these reports aren't easy available. The steep escalation of energy prices, together with concerns about market competitiveness, control of greenhouse gas emissions and energy supply security, added urgency to the need to examine the effectiveness of energy use in foundries. In doing so, improving energy efficiency should get proper attention. In table 2 the expecting areas of energy saving are shown. The table 2 is a compilation of results from many energy audits of Canadian foundries undertaken in the few past years by CANMET (Canada Centre for Mineral and Energy Technology).

Equipment / process	**Consumption of total plant energy, %**	**Area savings potential, %**	**Overall plant savings, %**
Melting	59	15	9
Fans and pumps	6	35	2
Lighting	6	30	2
Motors	12	10	1
Air compressors	5	20	1
Miscellaneous	12	10	1
Total	**97***	-	**16**

Table 2. Summary of expected results based on end use consumption[9]
* Variation due to unaccounted influences

[8] data according to Guide to Energy Efficiency Opportunities in Canadian Foundries, available on oee.nrcan.gc.ca/cipec/ieep/newscentre/foundry/index.cfm

Energy management is the strategy of adjusting and optimizing energy, using systems and procedures so as to reduce energy requirements per unit of output by keeping constant or reducing total costs of producing the output from these systems. The term energy management can be considered as consisting of three basic steps - planning, execution and control so an energy management program follows the same principles that apply to any purposeful undertaking (e.g., to quality and environmental management systems) - principles that Dr. Deming formulated as the cycle: Plan - Do - Check - Act, (PDCA). As all effective activity the energy efficiency effort must have a defined focus, accountability and responsibility. Therefore the first assignment in energy saving activity must be the initial energy audit. It is a key step that establishes the baseline from which the future energy efficiency improvements van be measured. One of the main results of energy audit is the possibility of determination of the energy consumption pattern. The energy pattern is the key in understanding the way energy is used in a foundry and helps to control energy cost by identifying areas where waste can occur and where scope for improvement may be possible. Subsequently every process must be made accountable for optimum energy usage and quantified study should be made for energy savings. The results shown in table 2 can be very helpful in these proceeding. The management must formulate a plan for usage of energy and make a step-by-step procedure for its implementation.

So we can try to summarize the necessary steps for creating the energy management program for foundries:

• Foundry energy audit

• Identify foundry opportunities

•Evaluating impacts of foundry opportunities

• Prioritizing foundry projects

• Implementing energy management program as a part of foundry management system.

There are some of key problems concerned to mentioned procedure. The first we have to start up are the energy and material (mass) balances. They serve to account for all energy inputs and outputs (including waste streams) for a given balance type. Balances which ought to calculate first of all are:

• Power balance

• Coke, natural gas (and/or oil) balance

• Steam and condensate balance

• Water balance

• Material balance (from raw material to good castings)

• Sand balance,

• Cores fabrication balance etc.

Looking for energy losses, one should also pay attention to the process equipment and how it is used. For example, assess melting and holding furnaces and their lids; the state of their repair; how the ladles are preheated; how the molten metal is conveyed, handled and poured; what the temperature gradients are at each stage; etc.

As well as straight energy consumption, we ought to consider examining casting yield and scrap rate and how the scrap is utilized because casting yield greatly influences materials and energy consumption. The next key problem is connected with heat wasting. Waste heat is the rejected heat released from a process at a temperature higher than the temperature of the foundry air. Even a casual look will show many sources of waste heat: in melting furnace exhaust, ladle preheating, core baking, pouring, shot-blasting, castings cooling, heat-treating, ventilation exhaust, etc. O course we can find much more areas of energy saving like:

[9] Guide to Energy Efficiency Opportunities in Canadian Foundries, available on oee.nrcan.gc.ca/cipec/ieep/newscentre/foundry/index.cfm

- Cupola start-ups and shutdowns
- Induction furnace preheating
- Furnace dust collectors
- Cooling water
- Sand-cooling equipment etc.

In production activity not only shown above exemplary ones but all emissions should be monitored continuously Monitoring data should be analyzed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken. A process which needs a minimum energy is least polluting for the environment.

Conclusion

- As it was shortly presented above, identifying energy management opportunities we can find the following broad categories:

- Organizational changes - the changes in planning and scheduling production in a way that allow for a partial or across-the-board leveling of energy use, hence its better utilization;

- Process changes - improvements in process equipment and technological changes that result in reduced energy consumption;

- Energy efficiency of melting and possibility of fuel substitution - maximizing the efficiency of use and selecting the best source of energy (e.g., electrical power or natural gas);

- Electric power management - measures resulting in reduced electricity consumption, including power demand and power factor management, and cogeneration;

- Heat recovery - re-use of waste heat streams and their integration and prevention of heat losses in all forms (e.g., heat exchanger, insulation).

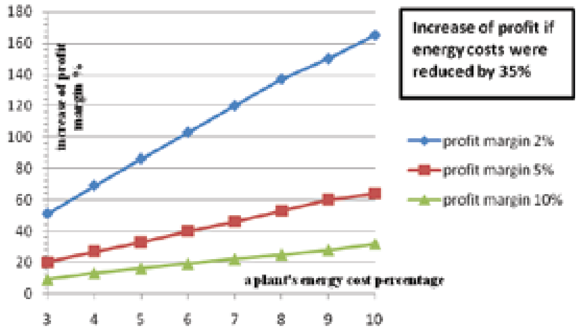

Figure 3 Estimation of profit increase from energy savings[10]

The initial individual list of projects should be scrutinized from several viewpoints. All available information, such as good engineering practice, experience of others, supplier information, literature, consultants and possible synergies ought to be examined. Monitoring energy performance helps managers identify wasteful areas of their department and lets them take responsibility for energy use. When monitoring shows that energy consumption is declining as improvements are being made, attention can be turned to the next area of concern. Of course the main tasks of our environmental efforts can't cover the maximizing of profitability. On fig. 3 the estimation of profit increase was shown in the situation when energy costs were reduced by 35%. We can easy find that the less current profit margin makes the bigger increasing of expected results.

In our present policy pollution prevention is preferable to reliance on end-of-pipe pollution control. Cleaner production encompasses production processes and management procedures that entail less use of resources than conventional technologies and also generate less waste and smaller amounts of toxic or other harmful substances. It emphasizes the human and organizational dimensions of environmental management, including good plant operation to avoid deliberate or accidental discharges.

[10] data according to Guide to Energy Efficiency Opportunities in Canadian Foundries, available on oee.nrcan.gc.ca/cipec/ieep/newscentre/foundry/index.cfm

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[1] Guide to Energy Efficiency Opportunities in Canadian Foundries, available on oee.nrcan.gc.ca/cipec/ieep/newscentre/foundry/index.cfm

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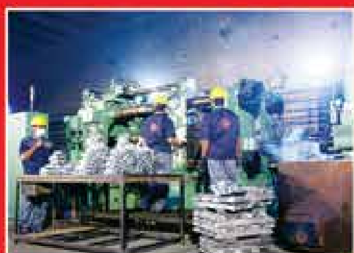

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Analysis of the requirements for foundry coke

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Abstract

Foundry coke is part of the mixture for melting of cast irons in coke oven and coke oven gas furnaces, which make up more than 37% of the domestic fleet of cast iron furnaces. It is obtained by sieving coal coke. Performing the function of fuel and providing the necessary heat, foundry coke has a significant impact on the stability of the melting process and the temperature of the cast iron. The share of energy and fuel in the cost of iron casting is 55-60%, so the reduction in coke consumption is of great importance for the energy efficiency of melting and the cost of castings. The requirements for foundry coke are currently set in the standard GOST 3340-88 “Foundry coke. Technical specifications ”, in which five indicators are normalized: mass fraction of total moisture, W_t^r , %; ash content of analytical sample, Ad, %; mass fraction of total sulfur, S_t^d, %; strength according to MIKUM, M40, %; fraction of pieces, less than 40 mm.

Introduction

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Literature overview

In the literature, the requirements for coke include: reactivity [1-3]; ash content [1, 4-7]; humidity [8-10]; strength [1-6]; porosity, density [1-6]; combustibility [5]; sulfur content [1-6]; the size of the pieces [1]; uniformity in size of pieces [2]. For example, it is believed that high-quality coke should have a piece size 10-12 times smaller than the cupola diameter [2]. As a rule, foundry coke has a piece size of more than 40 mm, and for cupolas with a diameter of more than 1.2 m - more than 80 mm to 150 mm [1,8-10]. Abroad, the requirements for the size of foundry coke are almost the same.

Two methods are currently used to assess the reactivity of coke: according to GOST R 54250-2010 “Coke. Determination of coke reactivity index (CRI) and coke strength after reaction (CSR)” and according to GOST 10089-89 “Coal coke. The method of determining the reactivity” (Table 1). Coke reactivity index (%) (NSC method of Nippon Steel Corporation) is used in foreign practice and currently in Russia.

Table 1: Comparative characteristics of methods for assessing the reactivity of coke

Distinction	Methods for determining reactivity	
	GOST P 54250-2010	GOST 10089-89
Indicator designation, units	CRI, %	K, cm3/g·s
Formula for calculating an indicator	$CRI = 100 \cdot \frac{m_0 - m_1}{m_0}$, where m0 – sample weight before reaction, g; m1 – sample weight after reaction, g.	$K = \frac{V \cdot T}{m \cdot T_1} R$, where V – carbon dioxide feed rate, cm3/s; T – test temperature according to test thermocouple, K; T1 – carbon dioxide temperature, K; m – mass of carbon in a sample of coke, g; R – reagent gas conversion.
Indicator values	20-35 [11], 45,8; 38,0; 38,6; 36,8; 30,3 (ERCI)	0,51-0,76 [12]
Sample requirements for analysis	Weight 200±2 г g with a particle size of 19,0-22,4 mm	Weight 7-10 g with a particle size of 1-3 mm
Analysis conditions	Temperature 1100±3 0C; carbon dioxide feed rate 10±0,25 dm3/min; test time 120 min	Temperature 1000±5 0C; heating rate not less than 100 0C/min; carbon dioxide feed rate 3 cm3/s; test time 15 min

Reactivity determines the efficiency of coke use in the cupola [11-12]. The gasification reaction contributes to coke overspending and cupola cooling, besides, the formed carbon oxide cannot be used [13], which generally reduces the melting efficiency. Therefore, coke with the lowest possible reactivity (< 0,5 cm3/(g·s) is required for foundry [14]. The best varieties of domestic foundry coke have a reactivity of 0,4-0,5 cm3/(g·s) [2].

The ash content (Aa, %) is an indicator of the quality of foundry coke according to the requirements of GOST 3340-88 and depends on the brand of foundry coke. The ash content should not exceed 12.0% for coke of the KL-1 brand, 11.0% - for coke of the KL-2 brand, and 11.5% - for coke of the KL-3 brand. The composition of ash in coke is determined according to GOST 10538-87 “Solid fuel. Methods for determining the chemical composition of ash” and GOST R 54237-2010 “Solid mineral fuel. Determination of the chemical composition of ash by the method of atomic emission spectrometry with inductively coupled plasma”, ash content according to GOST R 55661-2013 “Solid mineral fuel. Ash determination”.

Main part

The coke ash in Russian plants is significantly higher than in European ones. This is explained by an increase in the ash content of coal concentrates from 9.6 to 10.5% according to GOST R 51588-2000 “Coals and anthracites of the Kuznetsk and Gorlovsky basins for technological purposes. Technical specifications”, as well as the lack of price differentiation depending on the ash content of coal [15-18]. Hence, the ash content in coke for foundry is in the range of 11-12%, and in some cases even higher (13-14%) [2].

The moisture content according to the requirements of GOST 3340-88 is also an indicator of the quality of foundry coke. The share of total moisture in the working condition of the fuel (Wp, %) does not depend on the brand of coke and should not exceed 5.0%. The moisture content in coke is determined according to the requirements of GOST 27588-91 "Coal coke. Method for determination of total moisture", GOST 27589-91 "Coke. Method for determination of moisture in an analytical sample".

Humidity of coke in the plants of the European Union varies in a significant range (7.0-3.5%). Particularly high humidity is in some varieties of coke imported from China (9.5%). Minimum humidity (0.1-0.5%) is obtained by dry quenching of coke [4, 16, 19-21]. In Russia, the moisture content in coke is from 0.14-1.26 to 4.3-5.0%.

The sulfur content according to the requirements of GOST 3340-88 is an indicator of the quality of foundry coke and depends on the brand of foundry coke. The mass fraction of total sulfur should not exceed 0.6% in the KL-1 brand foundry coke, not more than 1.0% - in the KL-2 brand coke, and not more than 1.4% - in the KL-3 brand coke. In the supplied domestic foundry coke, the total sulfur content ([illegible], %) is on average 0.46-0.56%. Sulfur in coke passes from coal during coking. Methods for determining the forms of sulfur are presented in GOST 30404-2013 "Solid mineral fuel. Determination of sulfur forms", the total sulfur content in coke - GOST 2059-95 "Solid mineral fuel. Method for determination of total sulfur by burning at high temperature", GOST 8606-2015 "Solid mineral fuel. Determination of total sulfur. Ash's Method".

Phosphorus enters coke from a coal charge and is determined according to the requirements of GOST 1932-93 "Solid fuel. Methods for the determination of phosphorus". The phosphorus content in coke is very different and depends on the phosphorus content in the initial coals [4]. Mass fraction of phosphorus in coke ash at various metallurgical enterprises is presented in Table 2 [17, 21, 24-26].

Table 2: Mass fraction of phosphorus in coke ash at various metallurgical enterprises (P2O5), percent [17]

Nizhny Tagil	Chelyabinsk	Magnitogorsk	Orsk-Khalilovsky	Kuznetsk	West Siberian	Cherepovetsky	Novolipetsk number 1-4	Novolipetsk number 5-6	Kemerovo coking coal plant	Kaliningrad coke plant
0,35	0,65	1,00	0,70	1,10	0,65	0,25	0,60	0,60	0,31	0,55

Volatile substances are substances formed during the decomposition of coal under heating without access to air [18]. Volatile substances consist of adsorbed gases, especially air oxygen and carbon oxide [13, 27-28]. The content of volatile substances in coke is determined according to the requirements of GOST R 55660-2013 "Solid mineral fuel. Determination of the yield of volatile substances".

The amount of volatile substances of foundry coke (Vdaf, %) is from 0.5 to 1.5% [2, 16]. According to [20, 21, 29], the recommended amount of volatiles in foundry coke should not exceed 1.2%. The content of volatile substances in the supply of foundry coke according to GOST 3340-88 is not indicated. However, when technical specifications (TS) are developed, the developer usually adds the value of this indicator to the quality indicators for foundry coke. For example, according to the requirements of TS 0761-027-00187852-10 "Foundry coke. Specifications" the yield of volatile substances is normalized by a value of not more than 1.0%, and according to the requirements of TS 0761-028-00187852-10 "Foundry coal, coke produced by PAO "Mechel". Specifications" for coke with a grain size of 40 mm or more - not more than 1.2%.
Foundry coke strength is of great importance for the effectiveness of melting iron in a cupola furnace. For cupola melting, the strength of foundry coke against abrasion, discharge, shock loads, and also strength at high temperatures is of interest.

The following values of strength indicators are characteristic of domestic coke: M40 – 69-77 %; M25 – 83.7-92.3 %; M10 – 6.0-11.0 %; CSR – 32.6-58.2 %. For foundry coke, the strength value (M40, %) is established in GOST 3340-88 and ranges from 73 to 78% depending on the size class. The size of the coke provides charge permeability to gases and liquid melting products. The size of foundry coke according to the requirements of GOST 3340-88 is regulated by an indicator that limits the proportion of pieces smaller than 40 mm. Coke porosity is determined by various methods and it is characterized by the parameters of porosity ([illegible], %), apparent porosity (Pa, %) and bulk density in a large container (Z, t/m3).

Bulk mass in a large container according to the requirements of GOST ISO 1013-95 "Coke. Method for determination of bulk density in a large container" (Z, t/m3) is defined as the mass of coke per container volume. The bulk density depends on both the actual density and the apparent density and porosity. For cokes from Donetsk coals, the bulk density is 0.43-0.45 [16, 20], and 0.46-0.48 t/m3 - for cokes from eastern coals [20]. For foundry coke, the value of apparent porosity (Pa, %) according to various sources, ranges from 35 to 45% [2, 4].

The degree of completeness of the molecular and supramolecular structure of coke determines its properties as a semiconductor, characterized by a certain amount of electrical resistance. The value of electrical resistance can serve as an indirect characteristic of a number of properties of coke [22, 31]. For example, in [23], the relationship was established between the number of volatile substances characterizing the degree of "readiness" of coke and the completeness of thermomechanical transformations during coking, and the coke electrical resistance (ρ, Ω·m). The reactivity of coke is known to be reflected in the value of electrical resistivity: the smaller the ρ value of coke samples, the lower the reactivity index K [12, 24]. The data presented in [25] indicate the presence of a connection between the specific electrical resistivity and the valid density of coke (the correlation coefficient was -0.82).

The analysis of data on the rationing of requirements for foundry coke (Table 4) indicates the following:

- foundry coke has a large number of properties that affect each other;

Table 3: Foundry coke standardization

Number	Requirement	Designation	Units	Optimum values
1	2	3	4	5
	Reactivity	K	cm3/g·s	< 0,4-0,5
1	Reactivity after reaction with carbon dioxide	CRI	%	Not established
2	Ash content	Aa	%	< 12,0
3	Moisture of analytical test	Wp	%	< 5,0
4	Total sulfur content	S_t^a	%	< 0,6
5	Phosphorus content	P	%	< 1,2
6	Devolatilization	Vdaf	%	< 1,2
	Abrasion of coke after reaction with carbon dioxide	AV	%	Not established
7	Coke strength after reaction with carbon dioxide	CSR	%	Not established
	The strength of coke according to MIKUM	M40	%	≥ 73 ≥ 78
	Strength dropping	Shl	mm	Not established
8	Mass fraction of pieces less than 40 mm	-	%	≤ 5
	Porosity	P_r,	%	Not established
9	Apparent porosity	Pa	%	< 45
	Bulk density in a large container	Z	t/m3	Not established
10	Electrical resistivity	ρ	Ω·m	Not established

Conclusion

Insufficient attention to foundry coke indicates the absence of standardized requirements for foundry coke indicators such as reactivity, strength and abrasion of coke after reaction with carbon dioxide, dropping strength, porosity, bulk density in a large container, electrical resistivity.

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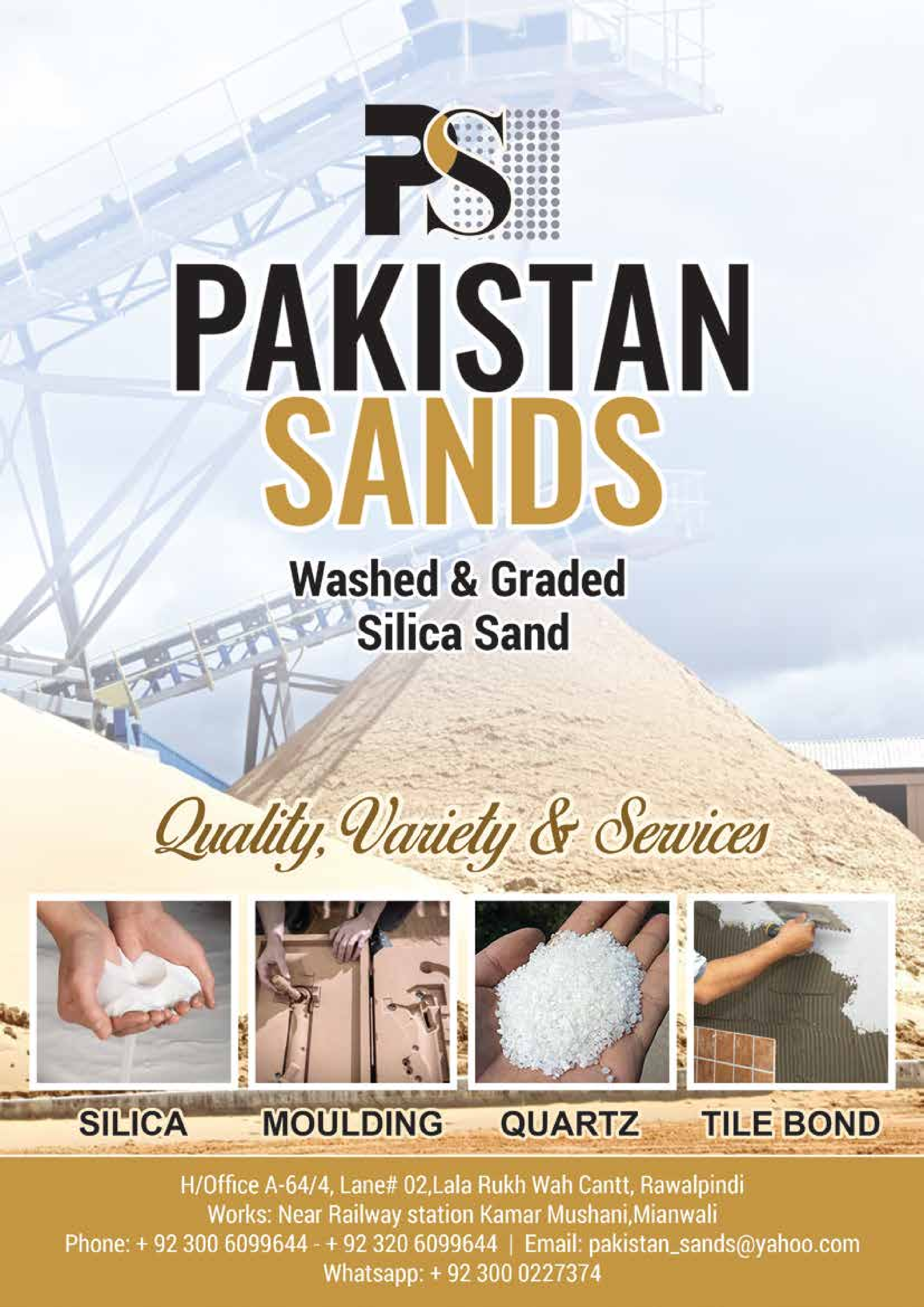
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Study on using Casting Simulation Software for Design and Analysis of Riser Shapes in a Solidifying Casting Component

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Abstract

Filling and solidification of molten metals are very complex and difficult to simulate correctly by conservative methods. For a large industrial application, it needs an alternate approach that is fast, reliable and user-friendly. In current casting industries, product development paradigm is shifting from traditional trial-and-error in the workshop to computer-aided casting design and simulation package by a computer(s). Computer-aided casting simulation plays an important role in the paradigm of new product development by way of modeling entire casting processes and reveals a dynamic behavior of casting scheme in working conditions. This study, highlighting is given on using casting simulation software which helps foundry industries to design and analysis the size and shape of the riser. Intended
for simulation simplification in this study, grain size of mold green sand, casting material quality, casting process parameters are deliberated identical for all design schemes. Only the shape and dimensional variances of sprue/risers are taken into considerations for defects analysis. It is found that defects such as micro and shrinkage porosities, and improper solidification, are directly related to gating and risers system. Casting simulation software is used for mold filling and solidification analysis and it is observed that the proposed gating and risers system design will improve casting results with small defects. From this study, the conclusion can be stated that taper sprue design, also acts as a riser, with an additional four small risers that will produce a small fraction of porosity inside of the casting part. Validation of simulation, in the future, will be proved through experimental trials in the foundry shop. **Keywords**: emission, environment, pollution prevention, energy management

Introduction

Casting, which comprises substantial metallurgical and mechanical phases, is an intricate procedure. The amount of solidification directs the microstructure mainly, which in turn controls the mechanical characteristics related to strength, hardness, machinability, etc. Location, size, and shape of a riser in a casting depend on geometry of casting, mold design and thermal properties of metal, and other process constraints. Riser which is designed wrongly will result either in imperfect casting with shrinkage hole or in lesser yield since directly solidification is not achieved. Therefore, correct design of riser system and process parameters with good control are essential for excellence castings. From representative concerns, experimental efforts are always enhanced for scheme and expansion of mold and to receive optimal procedure parameters. But, this effort is expensive, time unbearable, and maybe intolerable in some circumstances. Consequently, casting simulation procedure are a number of computeraided casting design and simulation software developed and used in foundry industries [1-3]. An integrated computer-aided casting software, consist of CAD and/or CAE system, simulates the way casting designers decide some casting procedure, cores, mold box, and mold layout, runners, gating system, and analyzes each choice to propose how the design could be improved to increase quality and to reduce tooling and industrial expenses. Simulation is a process of manipulative a model of an actual system and conducting virtual experiments with this model as the purpose of either understanding the behavior of the whole system or of evaluating various schemes for the operation of the system [4]. Main objective of using computer-aided casting design and simulation software to casting process is to offer maximum data on casting quality by predicting solidification occurrences and associated features, with a help of models that are made on obtainable details of clarifications during processes such as filling and solidification processes of heat transfer, fluid flow, microstructure formation and etc.

This study deliberates a presentation of some above main objective outputs obtained from simulation experiments with a commercial computer-aided casting design, Altair Inspire Cast 2019.2, as basic ideas of modeling and simulation of casting process to improve skill and knowledge of engineering students, foundry designers, and industries. Solidworks software package, as CAD software, was used to produce a three dimensional (3-D) model of cast parts, and the results were exported to Altair Inspire Cast as CAE software package employed to simulate the casting process goal.

Material and Methods

Computer-aided casting design and simulation programs are used for analyzing mold filling, casting solidification, internal distortion, and microstructure properties. The simulation programs are based on castings 3-D model of Finite Element Analysis and comprise innovative functions for user interface, computation, and display. Casting models (with feeders, gates, and/or runners) have to be created using a solid modeling system (CAD) program and imported into the casting simulation (CAE) program. Besides, part of casting material and mold properties, and process parameters (filling and pouring temperature, casting to mold heat transfer coefficient) have to be provided by designer.

This study has been passed in the following stages; these are studying in designing various parts of risers and gating system, and comparing the analysis of the other sources [5] and newly designed gating systems based on simulation results using Altair Inspire cast simulation software.

The procedure for carrying out a casting filling and solidification simulation program analysis is listed below.

- make some casting solid model such as casting, risers, and gates parts in CAD format (*.sldprt and *.sldasm) obtained from Solidworks software and then import them into Altair Inspire casting software o make and specify cast part, designate filling system, set gravity direction gating system, designate gate, define components such as risers and mold, define process parameters through basic setup
and gravity process, and finally run analysis

- carry out results simulation analysis to establish degree of filling and solidification results beside to a set of quality standard

- availability result types of filling and solidification simulations will show temperature, solid fraction, mold temperature during casting process, and many other results for every model scheme incorporating shrinkage percentage, in gate effects, etc. These analysis results in the model scheme being changed to the predicted final shape (internal and external) of the casting showing size, shape, and location of shrinkage cavities in castings and feeders. After executing the repetitive simulations, the results can be post-processed to view color-coded temperature profiles of mold, filling, and solidification, velocity vectors or residual stresses. This enables forecasting

After executing the repetitive simulations, the results can be post-processed to view color-coded temperature profiles of mold, filling, and solidification, velocity vectors or residual stresses. This enables forecasting some probable location of flaws. Finally, the results are reliable if the input data is complete and accurate.

The 3-D geometries are created by 3-D Solidworks software and the drawings are saved as the format of *.sldprt and *.sldasm. The simple model of casting geometry for this study is shown in Fig. 1 consists of linear and taper sprues, an additional one to four small riser(s) [5] and one to four runner [6] for the next study. The 3-D models are then imported into Altair Inspire Cast software which is used for numerical design and analysis simulation. The mesh adopted was tetrahedral with a total number of around 50.000 elements, which were divided by the self-module of Inspire Cast package.

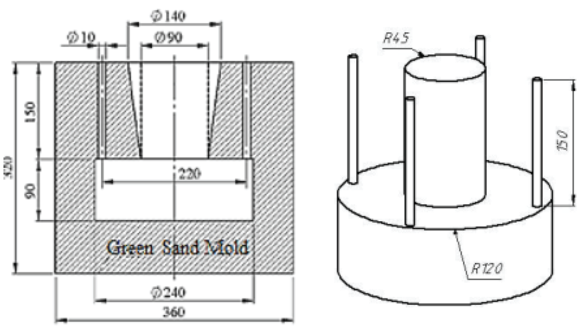

Fig. 1 Casting-mold cross-section and 3-D Cad drawing

Three dimensional (3-D) solid models of casting components consist of a cylindrical casting part, cylindrical and taper sprues and additional four small risers have been imported into Inspire Cast software environment for estimation of defects. Casting details are as mentioned below. Casting material is low carbon steel (GS C-25), the mass (from auto calculate mass package) is 31.916 kg and volume is 4071.5 cm3 with pouring temperature is 1850 K and pouring time is 2 seconds, and casting method is green-sand casting with density of 1550 kg/m3 at 293.15 K, thermal conductivity of 0.60 W/m*K and specific heat of 1.10 kJ/kg*K at 1273.15 K [7]. Gating channels are created which is shown in Fig. 1, the sprue position is certain, which is connected to ingates through the risers. The simulation program has been performed for mold filling and solidification analysis to check various locations of defect formations in the casting component. This simulation has helped in identifying the defect locations and proper location of riser(s) and some shapes of sprues, etc

Related to conclusion of [5], that is, conical (taper) riser with the same dimension of its linear base riser will be considered that the end of solidification occurred in the upper part of the riser, because the riser with the resulting shrinkage cavity is cut off and re-processed. Then scheme I of simulating design is the mold consists of a casting part with each has a taper and linear sprue shapes on top of the part and by casting software will be designated as ingate and also act as a riser. The whole assembly is shown in Fig. 2.

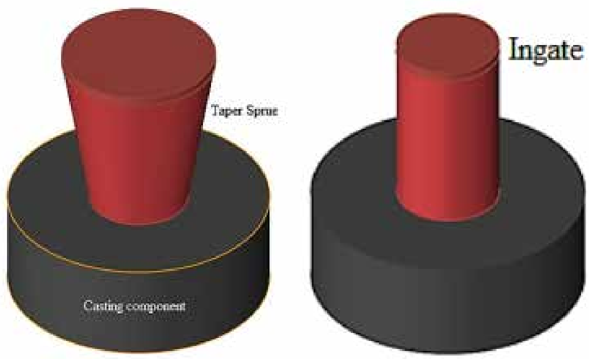

Fig. 2 3-D casting design model for taper and linear sprue of a scheme I

Scheme II: based on scheme I, the mold consists of an additional four small risers on the top of casting component, as shown in Fig. 3. Four risers will be located in opposite direction and each of the risers will distance by 110 mm from the center of casting component.

For sand casting as mold components, set on 200C, need several important considerations. The part must be designed for worthy fluid flow paths of incoming liquid metal to enter the mold cavity and must be designed with adequate heat transfer paths to allow for favorable cooling as the part solidifies with a specific pattern of solidification, referred to

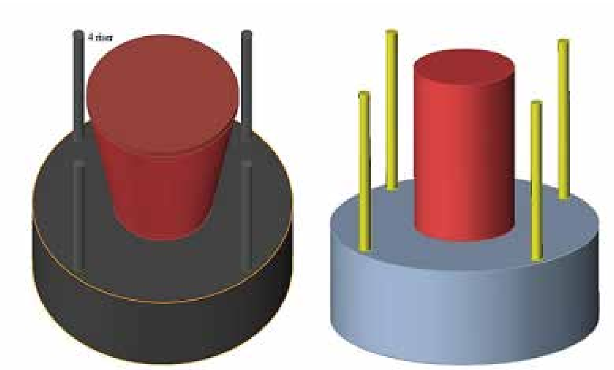

Fig. 3 3-D casting design model with additional small risers of scheme II

as directional solidification, and solidification time. Finally, green sand molding utilizes a pattern for producing the mold cavity in sand [8].

Results and Discussions

Simulation results of mold filling processes of scheme I-II are shown in Fig. 4 and 5. The molten metal flowed from linear and taper sprue also (act as risers) along the ingate directly, so increasing the shock to the mold. The molten metal first filled up the sprues at maximum pressure around 0.02 MPa. When the filling volume was 50%, the molten metal began to fill the half of casting smoothly from the bottom, but it splashes more in the linear sprue while filling smoothly in the taper sprue. This mold filling process with the taper sprue is more acceptable.

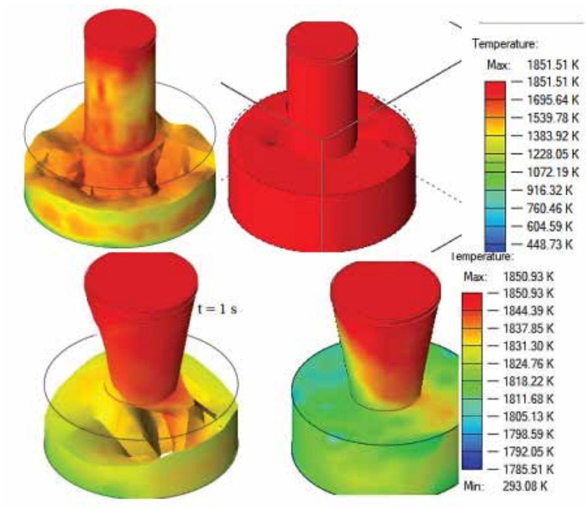

Fig. 4 Filling temperature scheme I

Based on the above explanation, filling processes with an additional four small open risers beside the central riser (sprue), Fig. 5, have totally moved the whole hot spots from the casting component.

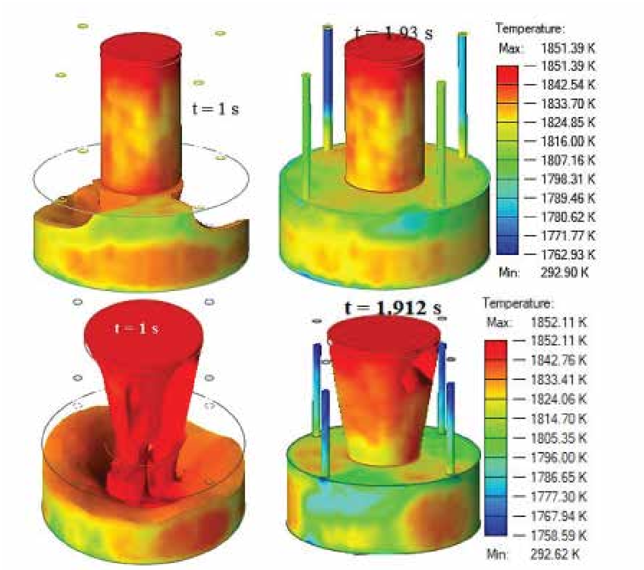

Fig. 5 Filling temperature scheme II

Solidification simulation is preceded by using the temperature field just after mold filling. Fig. 6 and 7 show the solidification results and a color bar indicates the solidification time. The transparent frame indicates the solid metal.

From both figures, it can be observed that the four small risers are the first to solidify, and then the rest of the material gradually solidified progressing toward the casting component hub. When the solidification time was t = 889 s, the rim to center of casting component began to solidify proceeding to its circular surroundings. It totally solidified at the lowest, t = 1752 s (Fig. 6) to the highest t = 1948 s (Fig. 7). After the casting solidified slightly complete, it appears that the casting component with linear riser/sprue was the last area to solidify compared with at the sprue itself in the taper sprue. Viewing the whole solidification, the casting component is well described by progressive solidification.

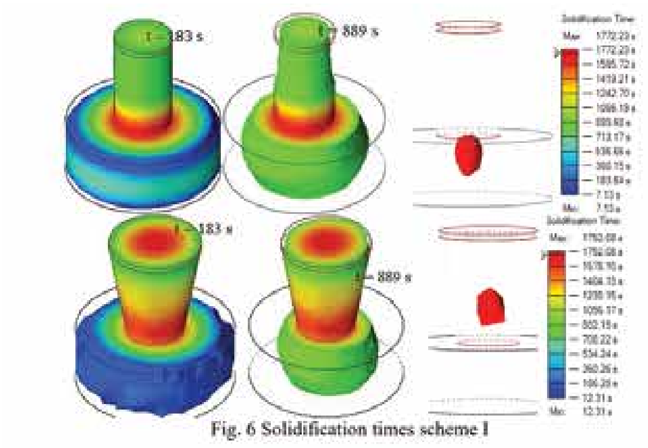

Fig. 6 Solidification times scheme I

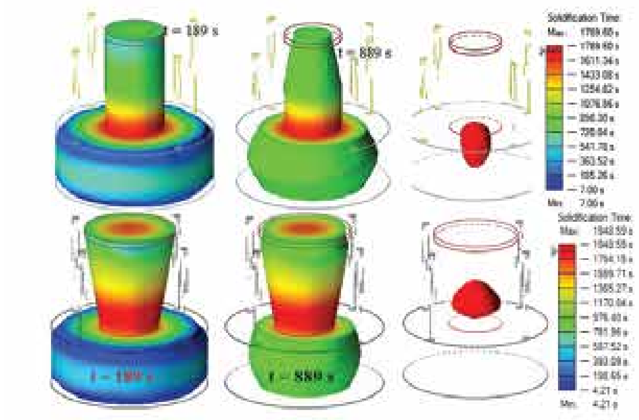

Fig. 7 Solidification times scheme II

Several imperfections formed are closely related to factors of molten metal pouring and design of gating system. Shrinkage of the metal is another reason for the formation of these imperfections. Certain parts of the casting should be equally fed from a sprue or riser(s) by liquid metal as a process of solidification is in progress. In a situation when feeding by molten metal of the casting solidifying part is interrupted, then empty spaces or micro porosities are created which will decrease the strength properties of the results [5]. Based on the explanation of point 4.2, although the microporosity has moved to the risers for both sprue shapes with and without additional risers, it is obvious that porosities still happen in both linear and taper sprues. Comparing both sprue shapes, the porosity in linear sprue still located in the casting component with and without additional small risers, but only a small part of porosity still located in the other shape sprue especially with additional four small risers.

4. Conclusions

Computer-aided casting design and simulation package, which involves virtual processes, can replace trial and error experimental casting procedures. The simulation tool has flexibility of analyzing and visualizing in a color bar of mold filling and solidification processes, identifying critical locations, and identifying casting defects such as micro porosities and shrinkage porosities. The simulation scheme II result of taper sprue indicated that the mold filling was flatter and that no flapping happened. However, during the solidification process, micro and shrinkage porosities appeared in the transition zone of the casting component and riser(s) for both schemes. The reason for that is the imperfect solidification sequence. The simulation scheme I and II results indicated that the solidifying sequ encecould be improved by adding a layer of heat-insulating material [9], likes composite metal foam consists of metallic hollow spheres – made of materials such as carbon steel, stainless steel or titanium. This study has presented that defect location can be predicted by numerical simulation.

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