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THE STATE OF ART AND FORESIGHT OF WORLD'S CASTING PRODUCTION

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The state of art and foresight of world's casting production is discussed in the paper on the basis of the latest statistical data. The progress gained during the last few years in foundry engineering is shown as a way to further development of foundry technology.

Key words: *castings, foundry, foundry production, new foundry technologies*

Stanje i predmnijevanje svjetske proizvodnje odljevaka. Na temelju posljednjih statističkih izvješća, u članku se raspravlje o stanju i predmnijavanju svjetske proizvodnje odljevaka. Probitačan napredak tijekom nekoliko posljednjih godina u ljevačkoj industriji se pokazao kao putokaz budućeg razvitka ljevačke tehnologije.

Ključne riječi: *odljevci, ljevanje, ljevačka proizvodnja, nove ljevačke tehnologije*

INTRODUCTION

The casting production is considered as one of the main factors influencing the development of world economy. Actual capacity of the world's casting production, which is higher than 60 million metric tones per year, is strongly diversified. The last decade brought significant changes in the world map of the greatest casting producers. Globalisation and transformation of economic systems is reflected by variations of foundry production in different countries, moreover the globalisation of economy is regarded not only as a chance but also as a menace for the European foundries.

SOME COMMENTS ON THE HISTORY OF FOUNDRY

When considering the development of foundry engineering in a historical aspect we tend to connect it with the development of the human civilisation and to attribute to it the high position among the oldest world professions. In the times, from which the written sources are available, such as Biblical verses, Egyptian drawings or illustrations on ancient Greek vases (Figure 1.), existed already an advanced casting handicraft intended for religious cults, statues and armament elements.

Foundry production of middle ages consisted first of all of bells, baptismal fonts, temple portals, grave plates, cannons and other equipment for war purposes. Significant development of the production technique and work organisation took place within guild associations of bell-founders and smelters.

Figure 1. **Ancient Greece; bronze statue casting circa 450 BC [1]**
Slika 1. **Drevna Grčka; brončana statuta odljevena oko 450 godina prije Krista [1]**

The invention of printing by Gutenberg (1420) played certainly an important role in the development of low-melting non-ferrous metal casting. An intensive search for production methods for type-metals for whole founts led to inventing of pressure die casting and machinery casting (W. Church - 1822, D. Bruce - 1838, J. Sturgis - 1849).

Contemporary history is a continuation - in a global aspect - of scientific research and popularisation of inventions of a threshold importance. For foundry engineering it means the continuous period of introduction of enormous amount of the new versions of technologies, new materials, new applications and innovative metallurgical processes

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(electrometallurgy) as well as a real revolution in the production management.

The driving force of the foundry engineering is currently the automotive industry, which requires quality castings produced by means of practically all available technologies and casting materials. The transfer from production in natural moulding sands to a serial production in synthetic ones occurred.

The quality of castings obtained from special alloys reaches the level, which meets the requirements of a cosmic technique. The progress and advancement of the material engineering science gained lately allow obtaining the strength properties of alloys and composites like from the fantasy-land.

ESTIMATION OF THE CURRENT SITUATION IN THE WORLD'S CASTING PRODUCTION

The estimation of the current state of the world's casting production can be done either globally or with dividing into kinds of casting materials, or taking into account factor encompassing countries of the given continent. In this last case it is possible to separate four groups of the countries, producers of castings, according to the statistical data published in Modern Casting [2] (see Table 1.):

Table 1. **World's Annual Casting Production (total) - in kiloton's and indexes illustrating changes in production volume occurring during 1991-2001 (according to [2] and [3])**

Tablica 1. **Godišnja svjetska ljevačka proizvodnja (ukupno) - u kilotonama, a indeksi daju promjene ukupne proizvodnje tijekom 1991-2001 (suglasno [2] i [3])**

Annual Casting Production Volume (total) - in kilotonnes								
Country	Group	1991	2001	2002	2003	2004	2001:1991 quotient	1991:2001 % change
USA	I	8839,3	11871,0	11811,7	12069,6	12314,1	1,343	+34,3
Russia		18000,0	6200,0	6200,0	6200,0	6300,0	0,344	–65,6
China		10750.0	14889,0	16261,6	18145,9	22420,4	1,385	+38,5
Japan		7958,7	5841,2	5751,8	6111,4	6386,5	0,735	–26,5
Total (group I)		45548,0 (70,2%)	38801,2 (61,6%)	40025,1 (60,3%)	42526,9 (61,9%)	47421,0 (62,8%)	0,851	–15,0
Germany	II	4336,7	4643,4	4595,4	4722,6	4984,5	1,071	+7,1
France		2351,3	2527,1	3918,2	2484,5	2465,6	1,075	+7,5
Great Britain		1307,7	968,2	886,3	1221,5	1273,0	0,740	–26,0
Italy		1881,5	2393,3	2440,6	2441,0	2442,3	1,224	+22,4
Spain		832,7	1572,3	1628,6	1149,7	1309,2	1,895	+89,5
Total (group II)		10709,9 (16,5%)	12104,3 (19,2%)	13469,1 (20,3%)	12019,3 (17,5%)	12473,6 (16,5%)	1,130	13,0
India	III	-	3155,0	3267,0	4038,0	4623,0	-	-
Brazil		1228,9	1760,0	1970,6	2249,4	2829,9	1,432	+43,2
South Korea		1452,5	1683,2	1713,5	1783,8	1857,3	1,159	+15,9
Taiwan		1454,6	1209,6	1441,4	1468,1	1451,8	0,832	–16,8
Mexico		847,0	1680,0	2030,0	1822,9	2185,2	1,983	+98,3
Turkey		553,8	905,8	921,6	955,0	982,0	1,197	+19,7
Total (group III)		5536,8 (8,53%)	10393,6 (16,5%)	11344,1 (17,0%)	12317,2 (17,9%)	13929,2 (18,4%)	-	-
Czech Rep.	IV	1327.0	471.9	441.15	477,1	522,4	0,356	–64,4
Poland		815.8	745.2	660.1	729,4	804,5	0,913	–8,7
Romania		850.5	36.5	365.5	365,5	207,0	0,390	–61,0
Hungary		93.6	121.6	136.8	253,0	164,9	1,299	+29,9
Total (group IV)		3086,9 (4,76%)	1703,7 (2,70%)	1603,65 (2,40%)	1822,0 (2,70%)	1698,8 (2,30%)	0,552	–44,8

The first group consists of countries of the highest castings production, such as: USA, Japan, China and Russia.

The second group contains highly industrialised countries of Western Europe: Germany, France, Great Britain, Italy and Spain.

To the third group belong the extra-European countries, such as: India, Brazil, South Korea, Taiwan, Mexico and Turkey, in which significant increase of production occurred during the last decade.

The fourth group consists of countries of Middle-East Europe: Poland, Czech Republic, Slovakia, Romania and Hungary.

Annual world's casting production and percentage participation of group of countries in world's volume of casting over analized period of time is shown in Table 2.

Previously, the first place belonged to the USA (11,871 mln tonnes), which in 2001 was overtaken by China (14,889 mln tonnes). Russia, after the decomposition of the Soviet Union, decreased its casting production from approximately 18,0 mln tonnes in 1991 to 6,2 mln tonnes in 2001, which means 65 % decrease [2, 3].

Casting production in Japan was gradually decreasing from 1991 (7,958 mln tonnes) to the level of 5,841 mln tonnes in 2001, which caused shifting Japan to the fourth place in the global casting production.

Out of the extra-European countries of a high dynamic of development the first place belongs to India (3,155 mln tonnes). Brazil is the second (1,76 mln tonnes) South Korea the third (1,683 mln tonnes) and Mexico the fourth one (1,68 mln tonnes). Taiwan (1,209 mln tonnes) and Turkey (0,905 mln tonnes) supplement the list of countries, where the total casting production achieved in 2001 - 10,3 million tonnes.

In the countries of the former Socialistic Countries (Czech Republic, Poland, Romania and Hungary) the significant decrease occurred already before 1991, thus values given in Table 1. do not fully represent the observed production decline. However, apart from the situation in Hungary, this decline continued in the investigated period (1991 - 2001).

As the result of social-economic changes in Poland, the domestic casting production in the last two decades of the 20th century decreased by 67 % [4]. During the analysed period the casting production decline occurred also in Great Britain (–48,5 %), Germany (–16,38 %), Belgium (–17,4 %) and Norway (–7,1 %).

Development of casting production in some European countries, estimated also for the period of the last two decades of the 20th century, is quite interesting. Statistical data for those countries are as follows: Finland (increase by 0.6%), Italy (+11,26 %), Portugal (+17,0 %), Holland (+20,8 %), Austria (+38,4 %), Sweden (+152,5 %), Spain (+165 %).

Table 2. **Total volume and percentage participation of group of countries in world's casting production over analysed period of time**

Tablica 2. **Ukupna proizvodnja i postotak sudjelovanja skupina zemalja u svjetskoj ljevačkoj proizvodnji unutar analiziranog vremenskog perioda**

Annual Casting Production Volume in kilotonnes					
Group of Countries	1991	2001	2002	2003	2004
I	45548,0	38801,2	40025,1	42526,9	47421,0
	64,30 %	56,80 %	57,07%	57,76%	59,48 %
II	10709,9	12104,3	13469,1	12019,3	12473,6
	75,72%	77,72%	19,18%	16, 32 %	75,62 %
III	5536,8	10393,6	11344,1	12317,2	13929,2
	7,82%	75,27 %	16,16%	16,70%	17,42%
IV	3086,9	1703,7	1603,6	1822,0	1698,8
	4,36%	2,49%	2,25%	2,52%	2,75%
Total	64881,6	63002,8	66441,9	68685,4	75522,6
	91,6%	92,2%	94,6%	93,3%	94,7%

Among the European Union countries the main casting producers are still: Germany (35,4 %), France (19,25 %) and Italy (18,2 %). The shares of Great Britain (9,0 %), Spain (8,4 %), Austria (2,3 %), Sweden and Belgium (1,3 % each) are much smaller. The remaining countries have only 3,8 % share.

The European foundry industry, according to data evidenced in statistical reports [2, 3], is the third largest in the world for ferrous casting and second largest for non-ferrous. The annual production of castings in the enlarged European Union amounts to 11,7 million tones of ferrous and 2,8 million tonnes of non-ferrous castings. Germany, France and Italy are the top three producers in Europe, with a total annual production of over two million tones of castings each. Together, the top five countries produce more than 80 % of the total European production.

The progress of material substitution for ferrous castings extended in recent years caused the share of iron castings in the output total to decline slightly, dropping, from 58,9 % in 2001 to 58,2 % in 2002. Producers of nodular iron castings held at the same time a share of 34,3 % in the output total, making an increase of 0,5 % compared to preceding year. Analogical data for malleable castings shown expansion of their share from 1,1 % in 2001 to 1,3 % in 2002. Share of steel castings in the output total in 2002 is dropping 0,1% (to 5,8 %).

General statement is that the total European production tonnage of ferrous castings has been stable over past five years, although some fluctuation have occurred for individual countries. The analysis of the presented data shows that the figures for Great Britain (as an instance) indicate a general declining trend in production output, whereas the trend for Spain is one of growth. In recent years, Spain has taken over the fourth position from Great Britain, with both having a production of over one million tonnes of castings.

The non-ferrous foundry sector has undergone steady growth since 1998. In general in most countries production has risen. The output of non-ferrous metal alloys is still dominated by light metal casting at a share of 75,1 %, despite a decline by 3,5 percentage points compared to the year before. The share of copper alloys went down from 10,1 to 9,8 %, and the share held by the producers of zinc alloys similarly shrank from 8,7 to 7,3 %. The noticeable in last two decades development in the market for aluminum and magnesium castings was mainly caused by a growing shift of the automotive industry towards lighter vehicles.

Although the production volume has remained relatively stable over the past five years, there has been a decline in the total number of foundries. Data on the number of foundries show that there has been a general decline in the number of foundries since 1998, with the loss of about 5 % of the existing foundries each year (now approximately 3000 units), which is also reflected in the employment numbers (now about 260.000 people). However, the foundry industry is predominantly still an SME industry, with 80 % of companies employing less than 250 people.

The foundry production which is now undertaken results from fewer units and less employees. This can be explained by progressive up scaling and automation in the foundry units. The relationship between unit size, production and employment is well illustrated in Figure 2.

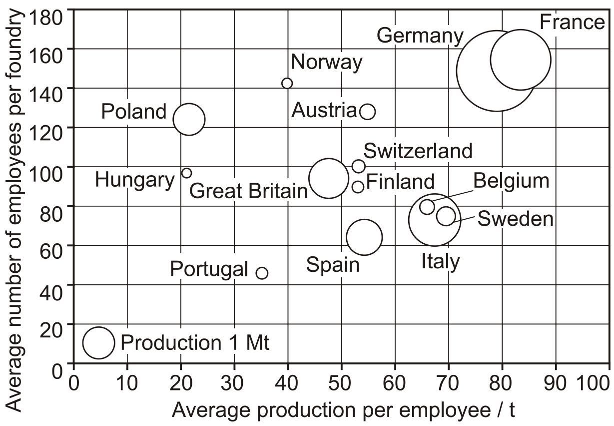

Figure 2. **Ferrous foundry productivity data for various European countries. Notice: the size of the circle represents the total production in specified country [5, 6]**

Slika 2. **Produktivnost čeličnog ljeva za različite evropske države. Napomena: veličina kruga predstavlja ukupnu proizvodnju u naznačenoj državi**

One can notice that the larger West European producers (Germany, France) are attaining higher productiveness with fever people. The more labor-consumption units are found in the Eastern and Southern part of Europe (Poland, Hungary, and Portugal).

The main markets served by the foundry industry are the automotive (about 50 % of marked share), general engineering (30 %) and construction (10 %) sectors. While iron castings mostly (i.e. > 60 %) go to the automotive sector, steel castings find their market in the construction, machinery and valve making industries.

IS THE FOUNDRY INDUSTRY AS THE PRODUCTION TECHNIQUE HAVING A FUTURE? …

Analysis of the world economy and its development trends indicates for the constantly growing share of foundry industry as the production and treatment technology of metal products. The biggest growth of casting production takes place in the countries being the economic leaders, in which it constitutes the significant part of the global income.

Continuous development of technologies and means of production did not cause any elimination of castings as a production technique, but - on the contrary - increased its importance and resulted in treating the foundry industry as a significant and constant element of the economic and civilisation development of nations. Direct shaping of metal products of practically every degree of complication, realised by the limited number of technological procedures, eliminating several additional operations - necessary when other production techniques are employed - constitutes still the basic advantage of this method, even when castings are in the range of the so-called "high-tech" (Figure 3.).

CHANCES AND DIRECTIONS OF THE FOUNDRY INDUSTRY FURTHER DEVELOPMENT…

The most important research directions leading to further development of the foundry industry:

- development of new technologies and casting alloys,
- melting and liquid metal preparation,
- preparation of casting materials and composites,
- manufacturing of moulds and cores,
- pouring, solidifying and cooling of castings,
- knocking out, cleaning and finishing of castings,
- technological waste management,
- new production systems and quality control.

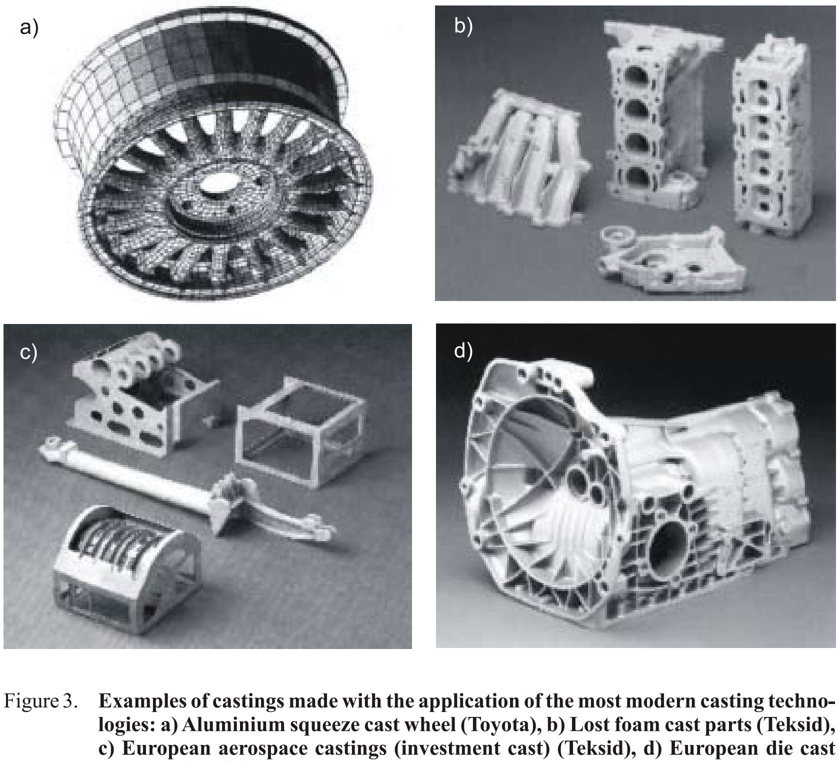

Figure 3. **Examples of castings made with the application of the most modern casting technologies: a) Aluminium squeeze cast wheel (Toyota), b) Lost foam cast parts (Teksid), c) European aerospace castings (investment cast) (Teksid), d) European die cast gear box (Teksid) [7]**

Slika 3. **Primjerci odljevka s primjenom najmodernijih ljevačkih tehnologija: a) Ljevački tlačena felga od aluminija (Toyota), b) Ljevački dio od pjenastog materijala (Teksid), c) Europski odljevci za svemirske letove (precizni ljev) (Teksid), d) Europski tlačni ljev kučišta (Teksid) [7]**

The comparison concerning directions, research advancements and their implementations into the foundry industry in the USA, Japan, and Europe is given in Table 3.

Table 3. **Comparison between the United States, Japan and Europe in Advanced Casting R&D and Manufacturing [7]**
Tablica 3. **Usporedba između SAD, Japana i Evrope u naprednom ljevanju R&D i proizvodnji [7]**

TECHNOLOGY	USA	JAPAN	EUROPE
Melting&Handling	XX	XXX↑	X
Alloys, Materials			
• rapid solidification	XX	XXX↑	XX
• metal matrix composites	XX↑	XXX↑	XX↑
Metal Mould Casting			
• gravity	XX	XX	XXX
• pressure die casting	XXX	XXXX	XXX
• semisolid moulding	XXX↑	XX	XXX↑
• squeeze casting	XX	XXXX	XX
Investment Casting	XXXX↑	XX	XXX
Specialized Sand Casting	XXX↑	XX	XXXX↑
Environmental & Energy Issues	XX	XXXX↑	XXX
Advanced Manufacturing / Process Development	XXX↑	XX	XXXX
Advanced Produkt Development	XX	XX	XX
Computer Design, Modeling, and Simulation	XXXX↑	X	XXX↑
Casting Equipment & Process Industry	XXX	XXX↑	XXX↑
Key: The number of X's indicates relative strength. Symbol ↑ denotes New developments and initiatives pointing to strength in the future.			

New technologies and casting alloys

Research will concentrate on the development and inventing new casting materials, which microstructure could be controlled on the molecular level. Investigations on amorphic and nanocrystalline metallic materials will be continued since they are characterised by unique properties:

- mechanical (high strength and resistance),
- physical (favourable magnetic properties [Fe-Co alloys], superconductivity [Mo and Nb alloys]),
- chemical (corrosion resistance).

Investigations will also concentrate on magnesium alloys, which are characterised by low density (they are 36% lighter than aluminium alloys), high resistance and excellent damping properties, good flowing power, possibility of treatment and regeneration. After solving problems concerning corrosion they will constitute the automotive sector future. Their application will significantly lower the weight of vehicles thus, contributing to environment protection by diminishing their negative influence.

Research related to ADI cast steel, which due to a high abrasion resistance accompanied with a very good ductility will find wide application in many industrial sectors substituting alloy cast steel or steel after thermal treatment, will be continued.

Casting in the semi-solid metal state (SSM)

Casting in the semi-solid metal state SSM found the application in thixocasting, rheocasting and thixomoulding processes [5, 8].

The thixocasting process utilises the technology of die casting of magnesium alloys, specially prepared before introduction into the die-casting mould. Thixotropic properties of material enable a laminar filling of die-casting moulds, which eliminates gaseous porosity of castings and non-metallic inclusions. Parts made in the SSM technology apart from good mechanical properties (resistance, elongation) are characterised by tightness, possibility of thermal treatment and welding. This technology allows substitution of expensive products obtained by plastic forming procedure by products made in conventional die casting machines of slightly changed parameters.

The casting process utilising rheological properties of alloys (rheocasting) was invented by the Japanese Company UBE Technologies. The most widely known

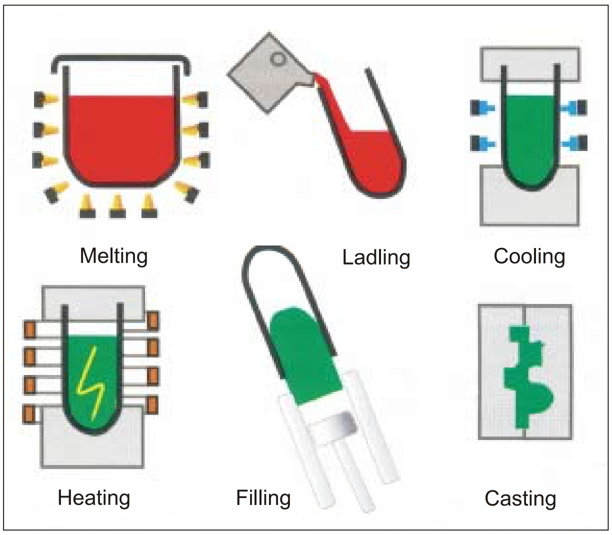

Figure 4. **Consecutive phases of the Rheocast process in the New Rheocasting version (NCR)**
Slika 4. **Uzastopni postupci Rheocast postupka u novoj Rheocasting varijanti (NRV)**

process version is New Rheocasting (NCR) developed by the Company in 1996. Pictorial diagram of the NCR process is given in Figure 4.

Thixocasting (Thixomoulding) is the third modification of the casting process utilising thixotropic properties of metals being in the semi-solid state. This technology was introduced in the middle of the last decade of the 20th century by the American Company Thixomat and has been constantly developing since then. Pictorial diagram and individual production phases of the Thixocasting process are presented in Figure 5. [5, 8].

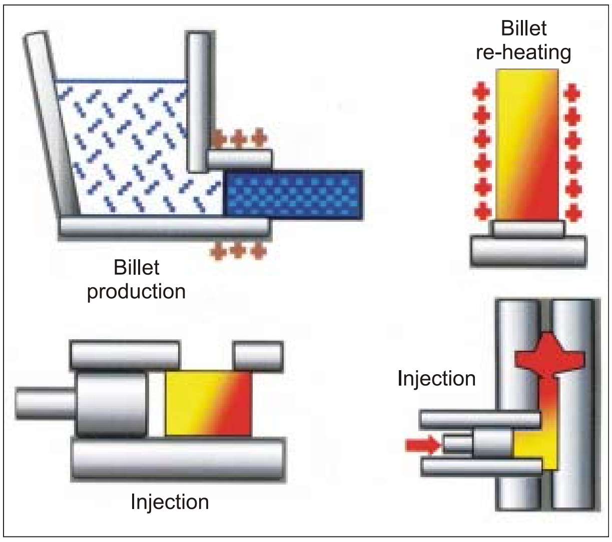

Figure 5. **Diagram and production phases of the Thixocasting process [5, 8]**
Slika 5. **Slijed i proizvodni postupci Thixocasting postupka [5, 8]**

Melting and the preparation of metal

An intensive development of induction furnaces of medium frequency, introduction of cokeless cupolas, with an output of 3 - 20 tonnes of cast iron per hour, as well as research aimed at significant energy saving (which has both economic and ecological importance) - can be noticed presently. Out of several novelties, being currently researched worth mentioning are:

- levitation melting, intended for alloys characterised by high chemical affinity to the furnace lining (e.g. TiAl). The melting process is performed either in a vacuum or in special protective atmosphere, which allows producing alloys of a good purity. Due to an inspection of electromagnetic phenomena there is a possibility of checking metal parameters without generating any turbulences;
- removal of non-metallic inclusions from melting metal by means of a constant magnetic field. Investigations carried on in Japan confirmed the method effectiveness in removing silicon contaminations from aluminium alloys. This can have great significance in the aluminium scrap processing.

Preparation of casting materials and composites

Procedures of material and composites preparation are essential for the quality of castings. A majority of casting defects is caused by an improper selection of casting materials and means of their processing [9].

Modern moulding sands circulations, characterised by the introduction of microprocessor process control systems and visualisations of several operations, will enable stabilising moulding sand parameters thus, improving qualities of moulds and castings.

Manufacturing of moulds and cores

Further progress in the methodology of moulding utilising air jet blown directly into moulding sands can be foresighted. Those are, apart from blowing methods: impulse moulding, moulding by air stream blowing through moulding sand followed by further press compacting, and the vacuum press moulding [10 - 12]. The renewed interest in a dynamic press moulding and vibratory-press moulding machines constitute a good forecast for their further application.

Flaskless moulding will further constitute the most economic method of serial production of moulds for the majority of small and medium size castings. The lower limit of serial moulds production depends solely on the costs of the model instrumentation, since the system of automatic changes of instrumentation enables model changing without the production interruption [13].

In the range of core-shop equipment and instrumentation the development trends concern mostly the technology of cores hardened in room temperatures.

Pouring, solidifying and cooling of castings

In modern casting plant these problems are inseparably connected with the computerisation and utilisation of new techniques and simulating tools. Techniques of computer assisted technologies being now-a-days useful tools of designing and production will become a must in foundries aspiring to survive in the market.

Computer aided techniques can be applied in:

- model designing in CAD system (aesthetic shape, geometry, volume, weight, etc.),
- simulation of functional properties at operating conditions (strength, resistance, durability),
- simulation of the production process (casting, thermal treatment),
- selection of treatment procedures and production (prototype, instrumentation, mechanical treatment, quality control).

Simulation processes will by applied in:

- designing and drawing of the shape of the model,
- dimensioning of the model,
- defining the boundary conditions,
- performing the simulation of pouring and solidifying processes as well as for the interpretation of the simulation results,
- selecting thermal treatment and determination of stresses.

Environment protection

The foundry industry is a major player in the recycling of metals [14]. Steel, cast iron and aluminum scrap is re-melted into new products. Most possible negative environmental effects of foundries are related to the presence of the thermal processes and the use of mineral additives. Environmental effects therefore are mainly related to the exhaust and off-gases and to the re-use or disposal of mineral residues. Emissions to air are the key environmental concern. The foundry process generates mineral dusts, acidifying compounds. products of incomplete combustion and volatile organic carbons. Dust is a major issue, since it is generated in all process steps, in varying types and compositions. Dust is emitted from metal melting, sand moulding, casting and finishing. Any dust generated may contain metal and metal oxide. In foundry process, emissions to air typically not to be limited to one (or several) fixed point(s). The process involves various emission sources (e.g. from hot castings, sand, hot metal). A key issue in emission reduction is not only to treat the exhaust and off-gas flow, but also to capture it.

Since foundries deal with a thermal process, energy efficiency and management of the generated heat are important environmental aspects. However, due to the high amount of transport and handling of the heat carrier (i.e. the metal) and its slow cooling, the recovery of heat is not always straightforward.

Foundries may have a high water consumption e.g. for cooling and quenching operations. In most foundries, water management involves an internal circulation of water, with a major part of the water evaporating. The water is generally used in cooling systems of electric furnaces (induction or arc) or cupola furnaces. In general, the final volume of waste water is very small. Nevertheless, when wet dedusting techniques are used, the generated waste water requires special attention. In high pressure die-casting, a waste water stream is formed, which needs treatment to remove organic (phenol, oil) compounds before its disposal.

The purpose of the Directive IPPC (Council Directive 96/61/EC) to achieve integrated prevention and control of pollution arising from the activities listed in Annex I, leading to a high level of protection of the environment as a whole [15].

One of the most important issues of the IPPC Directive is application of the BAT principle. The BAT descriptions contain mainly:

- characteristics of the process technology,
- specific production of emissions, waste and by-product generation, needs to consumptions of raw materials and energy inputs,
- the most effective technologies related to decreasing of emissions and waste rates and to increasing of energy savings,
- identification of BAT technologies,
- the new and developed technologies and processes.

CONCLUSIONS

European metalcasting industry, just as most European and USA manufacturing, suffered greatly from the early in this decade. Moreover, substantial dynamics in the global economy, especially off-shore sourcing of cast metal components as well as the off-shore manufacturing of durable goods that require castings continue to profoundly reshape European metal casting industry. The effects of the recession were magnified by the influx of low-priced castings from off-shore sources including Brazil, India and particularly China. Nowadays it is becoming clear that economic trends and technological advances are creating an inflection point in the growth rate for cast metals components. The growth in the world economy, particularly in such countries like: China, Russia, India and Brazil will fuel demand for casting related to transportation and an industrialized infrastructure. According to opinion of M.W. Schwatzlander and R.E. Showman [16] from Ashland Casting Solution Group, advanced in ferrous metallurgy, extraction metallurgy and materials processing will provide new alloys and casting opportunities that haven't been seen since growth of aluminum castings in the twentieth century. Improvements in casting design and manufacturing processes will finally convert the "black art" of foundry into a science.

Metalcasters need to invest in technology and in people. A meaningful improvements in casting design, modeling, prototyping and production will be of the highest importance if foundries want to achieve increasing the capabilities and lower costs.

Finally foundries need to invest in people. The knowledge and skills needed to keep pace are changing even faster than the technology. Over the next 50 years, new skills will need to be developed every three to five years. Ongoing training and education will be a must for successful foundries.

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