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A Review on Critical Casting Defect in Cast Iron: Sand Inclusion

Kollu Sathvic

Sree Vidyanikethan Engineering College, Tirupati, Andhra Pradesh, India.

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ABSTRACT

Sand inclusion is an important defect in Cast Iron castings. On an average this defect is almost thirty to forty per cent of the total defects occurring in a foundry. Sand inclusion is undesirable since it results in reduction in the strength of the casting and bad finish of the casting surface. More than hundred parameters are responsible for sand inclusion and hence it is difficult to control defect during casting. A detailed Literature review of the previous work mostly on sand inclusion for almost last fifty years is done in this paper to find appropriate parameters for defect formation of sand inclusion. From the literature review it is found that the exact remedy for sand inclusion is not easy. The papers describing different techniques like Quality Function Deployment, cause and effect diagram, Design of Experiments etc. are also referred for finding the appropriate parameters responsible for sand inclusion. Corrective action should be taken on responsible parameters to eliminate the defect and improve quality of ferrous castings.

Introduction

Castings play a very important role in manufacturing industry. Major applications and uses of castings are in automobile industry, agricultural industry, machinery etc. It is found that casting process is mentioned as shilpashastra in several Sanskrit works and dhamatri (cupola), gharma aranmaya (crucible), bhastri (blower) are the casting equipment mentioned in the Rigveda. The major application of casting was in creating the God idols used for worshipping which can be confirmed from the cast idols of Gods seen in our ancient temples. We hardly recognize our daily close association with castings through these cast God idols we worship.

Cast Iron components are produced usually in large quantity by sand casting process and give rise to thirty to forty different defects like sand and slag inclusion, blow holes, shrinkage etc. Sand inclusion is a major defect and the mould material itself is responsible for this defect. Component weakens because of sand inclusion and lack in properties like soundness, high fluid pressure resistance, high bearing strength etc. and results in bad surface finish. In a grey cast iron foundry, total rejection on an average is around 8 to 10 per cent. Rejection due to sand inclusion is about 30 to 40 per cent of this amount that is 2 to 4 per cent of the total rejection. This is a huge loss to the foundry considering wastage of the large amount of heat energy in melting the material, re melting of scrap, handling and inspection cost and has a demoralising effect on the employees. There are a large number of parameters to be controlled while manufacturing the sand casting and are broadly categorised as sand, moulding, melting and pouring parameters. Correct selection of parameters responsible for sand inclusion defect is very difficult task and hence this defect is very difficult to control. Literature review of previous work from papers related to sand inclusion ranging from year 1961 to 2014 is done in this paper to help in selection of correct parameters and elimination of the defect.

Sources and Types of Sand Inclusion Defect

There are various Sources for sand inclusion in ferrous casting. They can be in the form of cracking of upper mould surface and its deposition on molten metal called as sand drop. They may be because of cuts and washes because of impingement of molten material on mould surface at high speed and deposition of eroded, washed away sand elsewhere in the mould. The buckle or rattail, erosion, expansion scab, crush, dirt, sand rain, sand hole, sand fusion, raised core are some more types of sand inclusion defects.

Literature Review

The Fifty one papers selected for literature review mostly on ferrous casting defects and analysis of sand inclusion defect range from year 1961 to 2014. Eight papers out of these are from Elsevier, two are from Springer, three are from metal related journals from Poland, UK, and Switzerland. One is from online available papers, one from Industrial Engineering journal. Rest of the papers are from foundry related journals like, two from British Foundry man journal, two from 'Foundry' journal, five from Indian Foundry journal, four from Modern Casting, four from Casting Plant and Technology journal, one from Metal Casting, one from Metal Asia. The details of papers published in conference proceedings are two from British C. I. Research Association, one from American Foundry men's Society (AFS) transactions, one from proceedings of conference in France, one from CIRP Conference on Manufacturing Systems, three from annual conference proceedings of Indian Institute of Foundry men (IIF) FCON, three from annual convention of IIF, one from symposium on ductile iron, one presented in national conference, two from proceedings of international conference etc. as given below. One reference is from book. They are categorised into two main groups, one related to causes and remedies, the other related to defect analysis of sand inclusion.

Tele:
E-mail address: dhammwagh@gmail.com

Sand Inclusion Causes and Remedies

Following papers give information and suggestions by authors regarding casting process parameters, causes and remedies especially of sand inclusion defect in ferrous casting.

Meredith (1996) explained the effect of variables and its control to produce defect free castings. According to him, amount of ramming, jolting, squeezing, type of sand etc. decides the compaction density of green sand, which is checked and controlled in terms of mould hardness. He also observed that the strength of resin bonded sand is much more than green sand thus will help in reduction of sand inclusion. According to Kumruoglu et al. (2008) moulding and melting parameters like amount of sand ramming, specifications of the mould wall, type and quality of sand used, rate of metal pouring and its temperature etc. important for getting good quality sand casting.

Deshmukh et al. (2009) have discussed the problems like sand cut, wash, erosion etc. which give rise to sand inclusion defect. The paper highlighted possible causes like insufficient cohesive strength of sand, poor gating, defective drying of mould and core, improper casting and mould design, poor green strength, improper alignment of mould halves, careless pattern removal, failure to use nails and gaggers, poor condition of pattern, varying strengths developed in different layers of mould. The precautions like gating system redesign and relocation, mould cavity reinforcing, timely mould repair and due care while moulding, provision of more draft, provision of aligning devices, correct pattern stripping, use of nails and gaggers etc. should be taken to avoid the sand inclusion defect.

Ravi (2011) has presented a collaborative system for defect free castings in which integration of part design, tool design, meth ding, process planning optimisation and its feedback to part design is provided. He has specified important control parameters for each phase like wall thickness for part design, feeding and gating system for methods, pouring temperature for process etc. He has defined quality as conformance of 'as cast' parts with the design and categorised conformance in to three, geometry, integrity and property. According to him sand inclusion is the result of the integrity non-conformance characterized by metal melting and pouring process. The result of the survey of two hundred foundries given by him indicates 7.4% rejection because of integrity defects alone.

According to Brieger (2011) sand inclusion is a result of breakage of core, feeder etc. because of high compressive force, during complex shaped casting production. Woldert (2011) stated that the proper quality of moulding sand can be obtained by maintaining the specific values of sand parameters like loss on ignition(LOI), sand temperature, residual dust content etc. He related the quality of casting surface and binder consumption with sand quality. Use of Furan resin sand moulds is suggested for getting high sand strength to large size casting moulds which will avoid sand inclusion defect.

Meredith (2012) studied automatic machine mould production and pouring on the same machine using vertical parting line moulds and found that the high melt flow rate during pouring on these machines essential to maintain lower pouring time as compared to mould production rate, may result in sand inclusion defect.

Ransing et al. (2013) expressed difficulty in relating the casting defects found with foundry process parameters. The different parameters considered by him for different processes are wall thickness ratio, temperature ratio, feeder modulus etc. for design, pouring speed, time, temperature etc. for pouring, melt temperature, preparation, composition etc. for melting and permeability, moisture content, GCS etc. for moulding.

Sand Inclusion Defect Analysis

The following papers give the different methods of analysis used for casting process and parameters involved during the process to ensure defect free casting.

Webster (1961) has stressed importance of testing sand parameters like green and dry strength, moisture, permeability etc. especially at high temperature to know tendency of sand mixture for crack formation or hot tearing of mould which will result into sand inclusion. He stated that this will help in arriving at simplest mixture at lowest cost for good quality castings. According to Greenhill et al. (1965) a defective casting is the result of reasons like movement of sand mould wall or collapse of core. Inadequate ramming, cores in green state, incomplete drying of cores etc. were the reasons considered for enlarged mould resulting into oversize, overweight and defective casting. The weighing or measuring technique is discussed to find iron casting soundness of any weight, size or shape.

Taylor (1988) suggested method of maintaining the same sand properties by adding new sand of one tenth of total casting weight in old sand and removing the old sand of same quantity. According to Greenhill (1988), high metal temperature results into core distortion defect and low pouring velocity results into scabbing defect in casting. The values of the pouring speeds to avoid core distortion and erosion for simple as well as complicated components like valves are suggested by him. Dobiejewska (1988) used clay binder's differential thermal analysis curve (DTA) for prediction of quartz clay sand properties. He stated that the bonding strength of kaolinite and montmorrillonite (bentonite) clay depends on their water absorption capacity and strength of moulding sands depend on these clay minerals. He found that the area under differential thermal analysis curve is related to the water absorption capacity of the binder or clay [51]. The more the area, the greater the water absorption capacity, means the strength of moulding sand increases as the absorption capacity increases.

Nwajagu et al. (1989) have conducted experimental study in which kaolinite clay is used as a binder for 0.25 (sixty mesh) and 0.315(fifty mesh) grades of moulding sands. The effect of per cent of clay and water by weight on the parameters like permeability, compressive and shear strength were studied by calculating moisture sensitivity, friability and collapsibility. It was observed that the finer, 0.25-grade sand with the 14% by weight of ukpor clay exhibits better overall moulding properties and showed lower gas permeability. It was also observed that addition of 4 % water lowered the friability and collapsibility of the mixture from 12.53 to about 1% and addition of 3% sawdust increased collapsibility without any significant change in friability.

Loto et al. (1990) investigated the effect on moulding properties by varying the amount of clay, tempering water and sand. It was found that igbokoda clay could be substituted for the bentonite when clay content is higher and the optimum green strength could be attained with a lower percentage of clay addition when pre-treatment of the clay is done. It was observed that good moulding properties can be obtained by blending the bentonite and the igbokoda clay. Hornung (1990) has discussed the different methods for defect detection like visual assessment, occurrence survey, metallographic examination and chemical analysis etc. in the castings.

He suggested the visual examination to be carried out by observing details of defects like shape, size, internal characteristics, location etc. for example shiny or blue gray lining is considered as sign of inclusion. He suggested use of scanning electron microscope and electron microprobe to distinguish between the sand grains and oxides and also its use in deciding the type of defect as sand or slag inclusion which otherwise is difficult to distinguish. The causes for different defects formation and corrective action to be taken to eliminate it are recommended. Wiese (1990) has prepared a model of solidification stresses for grey iron casting in ANSYS and compared the stresses developed by movement of hot metal against sand mould and its permanent deformation by applying related boundary conditions using two methods. He stressed that the relationship between sand inclusion and stress value can be found by doing more research.

Bex (1991) has suggested control of sand inclusion by optimum permeability selection. He stated that modelling and change of parameters like mould cooling, permeability etc. can be done in simulation software Easy Flow. Lessiter (1992) stated that sand testing and control is essential for preventing most sand related defects. He gave the example of too high working bond level which results into penetration, blow and poor finish. He suggested the way to find green tensile strength from splitting strength as it gives an idea about ability of sand to get drawn from pattern pockets after mould preparation.

Krysiak (1994) pointed out four basic variables like water addition, new sand, bond and carbonaceous material to be monitored for green sand control. He stressed importance of testing sand parameters like AFS grain fineness, permeability, density, specimen weight for new sand additions, methylene blue clay, AFS/25 micron clay, green strength for bond control, moisture, compatibility for water addition control, loss on ignition for carbonaceous material control, temperature test, to control green sand system for good quality castings.

Pathak et al. (1994) have done overview of organic binders like no bake, hot box, cold box binders etc. in the paper which is helpful for selection of appropriate binder for the product. The productivity, quality of casting said to be improved by selecting suitable binders which will also reduce sand inclusion and pollution.

Guleyupoglu (1997) listed the thumb rules for components of feed system design like sprue, runner, gate etc. used by experts from foundry and guidelines by researchers for different materials for getting defect free castings with better yield. He stated that the production of sound casting is by the use of well-designed rigging system which provides the requisite amount of molten metal all over the casting surface. He stated the rules for part orientation, parting plane, sprue, riser, gate, runner etc. for ductile iron castings. The rules give recommended locations of gating system, design guidelines etc. for components.

Zanetti et al. (2002) compared the processes like Gemco dry, Sasil and Safond wet mechanical treatment processes for green moulding sand recovery during core production. Parameters like thinness index, oolitic and some metals contents, acid request, coal dust etc. are considered for selection of process. They concluded that wet process can be applied for recovery of green moulding sands obtained from several foundries for cold box core production and better quality product whereas the dry process is applied to single foundry and for economic regeneration. Akarte et al. (2002) in a view to help in identification and improvement of critical parameters influencing manufacturability of components developed a systematic approach of evaluating producer and process at an early stage, in the form of Web based Integrated Casting Engineering (Web ICE) system. According to them, project formation and application programs have to be maintained in a web server and access is to be provided for process and producer selection, compatibility analysis etc. to the team of product, tooling and manufacturing engineers located anywhere. This is said to identify potential problems and prevent its occurrence by modifying product, tooling and process parameters suitably. The implementation cost is said to be almost zero. The manpower is to be trained to speed up its use in industry and to encourage researchers for developing similar systems in other areas.

Alagarsami (2003) has explained a systematic approach to defect identification, defect mapping and use of analytical techniques like Design of Experiments (DOE) to find root causes of the defect. According to him sand and slag inclusions are ambiguous defects. He stressed the importance of process data and defects documentation like time of making castings, location of defect in casting etc. for analysis of defect formation.

Siekanski et al. (2003) have prepared Ishikawa diagram for nonconformities during pouring operation of C.I. and considered sand inclusion as one of the reasons for mechanical failure of material. The data of foundry defects like sand hole, drop and sand buckle etc. is collected. It is concluded from the diagram that the poor casting quality is mainly because of negligence of employees, process parameters and procedures noncompliance etc. Jolly (2005) stated that the liquid front should not move too fast to avoid formation of inclusions.

Guharaja et al. (2006) used Taguchi's method for optimizing process parameters to reduce casting defects. Influencing process parameters were found by constructing Ishikawa diagram. Green strength, moisture content, permeability and mould hardness were found as most significant factors. Experimental results were obtained and Analysis of Variance (ANOVA) was performed. It was concluded that permeability is insignificant factor and green strength, moisture content and mould hardness are most significant factors for defects. Optimized values of green strength, moisture content, mould hardness, permeability were found out. Use of Taguchi method has led to improvement in productivity, increase in process stability, higher process yield due to significant reduction in casting defects from 25 % to 3%.

Kambayashi et al. (2007) have discussed about analysis of the defects like inclusion, pinhole, penetration etc. by using methods like Scanning Electron Microscopy, Energy Dispersion Spectrometer (SEM-EDS) and Electron Probe Micro-Analysis (EPMA). They stated that the sand inclusion defect because of exfoliation of core sand can be taken care of by increasing the mould strength, changing the casting method etc. The remedy for sand inclusion due to melting of green sand was given as increase in its surface stability, grain size control etc. Dhumane (2007) suggested the precautions like providing enough clearance between mould and core print, its careful fitting and cleaning etc. to avoid mould crush or sand particles deposition resulting into sand inclusion. Thareja (2008) stressed the need of reintroducing the process control measures to convert foundry from a weak to a strong manufacturing link.

Worker's training is considered on priority. Control on mulling speed, sand wastage, variations in process temperature and moisture were insisted.

Application of tools like 5 S, Total Preventive Maintenance, and ISO 9001-2000 based Quality Management Service model was stressed for improvement in quality, productivity and efficiency.

Parappagoudar et al. (2008) claimed that the moulding sand mixture is the major source of defects in sand casting. used a forward mapping (FM) or reverse mapping (RM) technique to express relationship of sand properties like permeability, GCS, mould hardness, bulk density etc. with input parameters like sand grain shape and size, quantity of water, binder etc. Back propagation (BPNN) or generic neural network (GNN) is used for solving problems in FM or RM. They have found that GNN performs better than BPNN. RM was carried by both approaches effectively.

Jaiganesh (2008) in his paper stated that the tool for different process variables and its effect for reducing process variation is DOE. He selected a Coimbatore based jobbing foundry for data collection of selected components based on consistency in production and number of defects. Pareto diagram was constructed to find vital few defects and it was observed that sand inclusion defect contributed to more than 50% rejection. He used DOE to reduce the process variability and sand inclusion rejection percentage. ANOVA was done for per cent defects due to sand. Conclusion was drawn that the GCS, mould hardness number and moisture are factors responsible for sand inclusion defect.

Tillmanns (2008) described in detail about different methods and machines for sand compaction. The flow ability of sand during mould filling and during compaction claimed to affect uniform mould strength and dimensional stability of mould. The bonding capacity of bentonite found to reduce flow ability and increase the mould strength. Author found scope for improvement in compaction process monitoring and control. Measures for improvement in flow ability of sand, design of squeezing tools, methods of compaction, function and application of air stream in conventional and flask less moulding etc. were given in paper. The duration of squeezing process was reduced, sand movement was improved. Advantages were reduced cycle time, mould quality improvement, optimum use of pneumatic energy etc.

Paluszkiewicz et al. (2008) using Fourier Transform Infrared Spectroscopy (FTIR) experimentally proved that the addition of dust into green sand does not lower its permeability or compression strength. The dust generated during preparation of green sand contains active bentonite, coal dust, silica sand etc. and is uneconomical to throw. Authors helped in lowering production cost of green sand and protection of environment by conducting this study. They also concluded that use of FTIR can be a tool for fast determination of mould sand defects.

Kermanpur et al. (2008) suggested use of filter in gating system for reduction in sand wash tendency by reducing turbulence of melt. Gursky (2008) stated that the sand erosion and sand inclusion risk can be lowered and stable and laminar flow can be obtained by use of ceramic filter at correct location and using optimum gating system design by referring to the results of study conducted at Hofmann Ceramic.

Mane et al. (2011) in their paper proposed an approach of defect classification and correct identification as per size, location appearance, identifying method, discovery stage and consistency.

New hybrid approach for the analysis of defect is proposed which is claimed to have benefits of both knowledge based and simulation based approaches.

The steps for proposed defect analysis of casting are given as application of DOE, comparison of analysis results with actual results, training of artificial neural network (ANN) algorithm, tuning of the simulation program to be done with the results if variation exists and consideration of effect of design parameters on occurrence of defects.

Dabade et al. (2013) has found permeability, moisture content, GCS etc. from the cause and effect diagram as the major parameters responsible for defects like sand drop etc. resulting into sand inclusion. Tools like DOE, ANOVA were used for analysis. Analysis of mean plots was used for finding optimum values of parameters and experimentation was done to confirm it. This helped in substantial reduction from 10 to 3.59% in rejection.

Chourase et al. (2014) have used DOE for green sand casting process parameter optimization. They found pouring temperature, pouring time, mould hardness, moisture content and gating system as the most influential factors for sand inclusion. The examination of these parameters by DOE is done, optimized values of these parameters are found and experiments are performed in small ferrous foundry. They found the acceptance level of casting to increase from 78.93% to 97.16% thus increasing productivity.

Summary

Casting is a foundry process which consists of many sub processes like sand preparation, mould making, metal melting, metal pouring etc. involving more than hundred parameters. Control of a particular defect by parameter control of only one sub process is not sufficient and thus one has to choose parameters from different sub processes responsible for that defect.

The commonly found foundry defects during casting are sand and slag inclusion, misrun, shrinkage, pinholes, blow holes, hot cracks etc. Out of these, sand inclusion, the difficult to control defect, can be because of problems like sand cut, wash, sand hole, sand buckle, displacement erosion, mould drop or sticker, raised core or corner scab, mould element cut off, raised sand, corner scab, broken or crushed core etc. The possible causes for these problems related to design are poor gating, faulty runners and risers, improper design of casting, mould and core, wrong design of pattern and match plate, insufficient draft etc. The probable causes related to material are inferior quality of resin, insufficient cohesive strength of sand, poor green strength, improper moisture content, defective drying of mould and core, incorrect permeability, improper mould hardness, high compressive strength etc. The causes like improper alignment of mould halves, poor condition of pattern, match plate, moulding boxes, moulding machine, sand, sand plant etc. careless pattern removal, failure to use nails and gaggers, improper procedure and parameter control during sand, gating, mould preparation, mould pouring, gases present in metal, negligent behaviour of employees etc. also give rise to defect formation. The elimination of these causes will result into sound, defect free castings.

Testing of sand is done to find parameters like green and dry strength, moisture, permeability, AFS grain fineness, density, specimen weight for new sand additions, clay content, compatibility, loss on ignition for carbonaceous material control etc. especially at high temperature. The analysis of defects and prediction of influencing process parameters can be done by preparing cause and effect or Ishikawa diagram.

The analysis of rejection and nonconformities is done by tools like Pareto diagram, cause and effect diagram, Six Sigma etc. Application of tools like 5 S, Total Preventive Maintenance, and ISO 9001-2000 based Quality Management Service model will be useful. Tools like Minitab, graphs etc. are useful for analysis and monitoring process variation and finding the root cause. Stress should be given on defect identification, defect mapping. Process data and defects documentation like time of making castings, location of defect in casting etc. is important for analysis of defect formation. Analysis of robust design factor values by ANOVA can be carried out. Fisher's test (F test) can be conducted on identified factors and respective pooled data. Taguchi's method is used for optimising process parameters to reduce casting defects. Experimental results are obtained and ANOVA is performed to find insignificant and

significant factors. Fourier Transform Infrared Spectroscopy (FTIR) can be a tool for fast determination of mould sand defects. Periodic review of process FMEA can result in increase in process reliability, quality and reduction in defects. Forward Mapping (FM) or Reverse Mapping (RM) technique can be useful to express relationship of sand properties with input parameters. Thumb rules for components of feed system design like sprue, runner, gate etc. used by experts from foundry and guidelines by researchers for different materials should be used for getting defect free castings with better yield. Use of Plasma Spectroscopy principle (LIPS) is stressed for sample less and contactless measurement of alloying elements in molten metal for control of process directly and automatically specially at night hours, for process stability and capability increase. Analysis of the microscopic defects like inclusion, penetration is done by using methods like Scanning Electron Microscopy with surface analysis equipment. Artificial neural network, historical data analysis etc. techniques are also applied. A systematic approach of evaluating producer and process at an early stage, in the form of Web based Integrated casting Engineering (Web ICE) system to identify potential problems and prevent its occurrence by modifying product, tooling and process parameters suitably with almost zero implementation cost.

The authors have done literature survey for mostly ferrous casting production but could not get the application of QFD to casting process. Hence two houses of QFD are prepared in two papers by Deshmukh et. al. (2010). From QFD critical part requirements having high column weightage were found out as, pouring temperature range, metal velocity and gating system. Further research is going on to complete remaining two houses to assure the production of defect free ferrous castings.

References

[1]Meredith, J. Factors which affect the soundness of graphitic Iron castings. *Metal Asia*, 1996, pp. 15.

[2]Kumruoglu, L. C. and Özer, A. Investigation of Critical Liquid Fraction Factor in Nodular Iron Castings by Computer Simulation. *Journal of Materials Processing Technology*, **197**, 2008, pp. 182–188.

[3]Brieger, G. D. -I. Optimized Feeding Systems Increase Quality and Reduce Finishing Costs. *Casting Plant and Technology*, **2**, 2011, pp. 53.

[4]Woldert, I. G. F. State of the Art Sand Regeneration System for Furan Resin Sand. *Casting Plant and Technology*, **2**, 2011, pp. 22–23.

[5]Meredith, J. F. Balancing Flow in Vertically Parted Moulds. *Metal Casting Technologies*, 2012, pp. 53–55.

[6]Ransing, R. S., Giannetti, C., Ransing, M. R. and James, M. W.A Coupled Penalty Matrix Approach and Principal Component Based Co-linearity Index Technique to Discover Product Specific Foundry Process Knowledge from In-Process Data in Order to Reduce Defects. *Computers in Industry*, **64**, 2013, pp. 514–523.

[7]Webster, G. C. S. Some Thoughts on Sand Control. *The British Foundrymen*, 1961, pp. 387.

[8]Greenhill, J. M. and Nicholas, K. E. L. Control by Weighing and Measuring of Production Iron Castings-A Method of Predicting Unsoundness. *The British Foundrymen*, 1965, pp. 43–48.

[9]Dobiejewska, E. Application of Differential Thermal Analysis in the Investigation of Moulding Sands. *Thermochimica Acta*, **135**, 1988, pp. 341–345.

[10]Nwajagu, C. O. and Okafor, I. C. I. A Study of the Moulding Properties of Sand Bonded by Ukpor Clay. *Applied Clay Science*, **4**, 1989, pp. 211–223.

[11]Loto, C. A. and Omotoso, E. O. Analysis and Development of Igbokoda Clay as a Binder for Synthetic Moulding Sand. *Applied Clay Science*, **5**, 1990, pp. 85–97.

[12]Hornung, M. J. A Systematic Approach to Cast Iron Defect Analysis. *Modern Casting*, 1990, pp. 33–36.

[13]Wiese, J. W. and Dantzig, J. A. Modelling Stress Development During The Solidification of Gray Iron Castings. *Metallurgical Transactions*, **21**, 1990, pp. 489–497.

[14]Bex, T. Solidification Modelling Reduces Casting Defects. *Modern Casting*, 1991, pp. 23–25.

[15]Lessiter, M. J. Putting Green Sand to the Test. *Modern Casting*, 1992, pp. 40–41.

[16]Krysiak, M. B. Reducing Casting Defects: A Basic Green Sand Control programme. *Modern Casting*, 1994, pp. 35–42.

[17]Pathak, S. N., Bharati, K. B., Ganguly, A. and Rau, R. H. G. Potential Organic Binders in a Foundry (Part 1). *Foundry*, 1994, pp. 13–26.

[18]Zanetti, M. C. and Fiore, S. Foundry Processes: The Recovery of Green Moulding Sands for Core Operations. *Resources Conservation & Recycling*, **38**, 2002, pp. 243–254.

[19]Siekanski, K. and Borkowski, S. Analysis of Foundry Defects and Preventive Activities for Quality Improvement of Castings. *METALURGIJA*, **42**, 2003, pp. 57–59.

[20]Jolly, M. Prof. John Campbell's Ten Rules for Making Reliable Castings. *JOM*, 2005, pp. 19–28.

[21]Guharaja, S., Noorul, H. A. and Karuppannan, K. M. Optimisation of Green Sand Casting Process Parameters by Using Taguchi's Method. *International Journal of Advanced Manufacturing Technology*, **30**, 2006, pp. 1040–1048.

[22]Kambayashi, H., Kurokawa, Y., Ota, H., Hoshiyama, Y. and Miyake, H. Evaluation with Surface Analysis Equipment of Casting Defects in Cast Iron Articles (review). *Materials Science Forum*, **539–543**, 2007, pp. 1110–1115.

[23]Dhumane, S. Automotive Components fro Cast Iron – Melting Practice and Defects. *Indian Foundry Journal*, **53**(12), pp. 42–46.

[24]Thareja, P. A Total Quality Organisation Through People. *Foundry*, 2008, pp. 77–84.

[25]Parappagoudar, M. B., Pratihar, D. K. and Datta, G. L. Forward and Reverse Mappings in Green Sand Mould System

using Neural Networks. *Applied Soft Computing*, **8**, 2008, pp. 239–260.

[26]Jaiganesh, V. Optimisation of Moulding Sand Parameters Using Taguchi's Design of Experiments. *Indian Foundry Journal*, **54**(7), 2008, pp. 43–55.

[27]Prof. Tillmanns, D. -I. H. The Mechanisms of Compaction in Clay Bonded Moulding Sands. *Casting Plant and Technology*, **4**, 2008, pp. 6–19.

[28] Paluszkiewicz, C., Holtzer, M. and Bobrowski, A. FTIR Analysis of Bentonite in Moulding Sands. *Journal of Molecular Structure*, **880**, 2008, pp. 109–114.

[29] Kermanpur, A., Mahmoudi, S. and Hajipur, A. Numerical Simulation of Metal Flow and Solidification in the Multi Cavity Casting Moulds of Automotive Components. *Journal of materials Processing Technology*, **206**(1–3), pp. 62–68.

[30] Gursky, S. H. New Theory on How Casting Filters Work. *Casting Plant and Technology*, **4**, pp. 28–33.