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SIMULATION OF THE CASTING PROCESS - A POWERFULL TOOL FOR ENCHANCED DESIGN OF THE CUTTING TEETH IN SURFACE MINING

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Recent development in the computer simulation technology caused a tremendous influence on a rapid prototyping in casting process. These computational tools facilitate engineering work and urge moulding verification in foundries. Among dedicated software packages the MAGMASoft is selected for availability reasons. Its effectiveness is proved with the simulation of moulding process of the cutting teeth for a bucket wheel excavator Use of MAGMASoft enables a shortcut to a forceful and durable product, without internal cavities and micro-porosity. Such advancement of the moulding process is described in this paper.

Key words: casting, porosity, wear, simulation, MAGMASoft

INTRODUCTION

Bucket-wheel excavator (BWE) normally operates in difficult exploitation conditions. Key element of BWEs is a steel made cutting tooth. Dominant criteria for selecting appropriate material, for the cutting tooth manufacturing would be: 1) good ductility 2) top hardness (to resist dynamic load) 3) resistance to abrasive wear. Regarding these criteria, molding arises as the most appropriate and affordable fabrication method. Since casting is the only product forming operation, the outcome properties mostly depend on the solidification process. Understanding of the solidification process means the true knowledge of the following items: 1) molten metal properties (temperature, composition) 2) crystallization conditions 3) Fe-C phase diagram

Prediction of the solidification course is a difficult issue, therefore this paper presents the advantages of MAGMASoft computational package application.

Unlike a traditional approach in casting parameterization which is regularly combined of theoretical calculus and empirical trials, MAGMASoft enables visualization and optimization of solidification conditions simply by virtual analysis. Main target in solidification is:

– Well formed microstructure
– Minimal micro/macro porosity

Improvement of these properties significantly increase fatigue strength and resistance to abrasive wear.

CUTTING TOOTH DESIGN

Economy of coal mining is of crucial importance for an efficient exploitation, and for that a primary goal in tooth design is development of a “split-part” concept [1]. This would be a simple assembly, composed of a dispensable cutting edge (CE) and steady holder (SH) (Figure. 1).

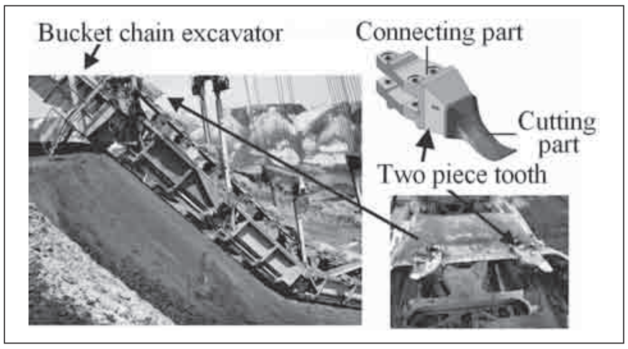

Figure 1 Cutting tooth on BWE

Thus the spare part becomes only cutting edge, which is replaced after being worn out. Steady holder remains in use for a long term operation as being unexposed to the wear. Part design, as well selection of appropriate material can significantly refine cutting edge performance. Fortunately material properties (abrasive wear resistance, ductility, hardness, dynamic strength etc) can be radically altered by appropriate casting technology in order to fit the operational conditions and improve cost/effect ratio.

CAD/CAM SIMULATION OF THE CASTING PROCESS

Casting process simulation (with MAGMASoft) requires a full 3D CAD model definition, i.e. definition of all the following segments: 1) collector 2) runner 3) drains 4) sprue 5) mold pattern and cores 6) gas drains 7) riser

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Properly designed pouring system assures fast and laminar flow of molten metal. On the other hand, turbulent flow may cause introduction of undesired inclusions such as: air, technical gasses or slag. These imperfections become the main reason of faulty casting. Pouring system should also prevent the entry of non-metallic inclusions, and allow gas drain from the mold cavity. Casting contraction while cooling, usually generates inner cavities and micro porosity in the last solidified zones. Implementation of larger risers can provide enough reserve of molten metal to fill the contracted casting. In order to prevent clogged pouring, a riser should be placed at the most voluminous and most outer point of the casting. Furthermore gas and air drains must be properly placed, to enable trapped air release. Normally, drains are at the top of the mold.

Aspects of the CAD modeling

In excavation, contact between cutting tooth and the soil occurs as an intensive cyclic pulse. Such a constantly repeating impact might cause a brittle fracture of the cutting tooth. Therefore presence of any micro porosity or hidden cavity can be fatal for structure integrity. In order to evade faulty casting, a virtual simulation can reveal possible defects, even at the early stage of mold shaping. For the conceptual design of a single mold for a coupled part casting (Figure. 2 a, 2 b), CAD model must involve: 1) casting shape and dimension definition 2) pouring system outline (sprue, runner) 3) riser size and disposition.

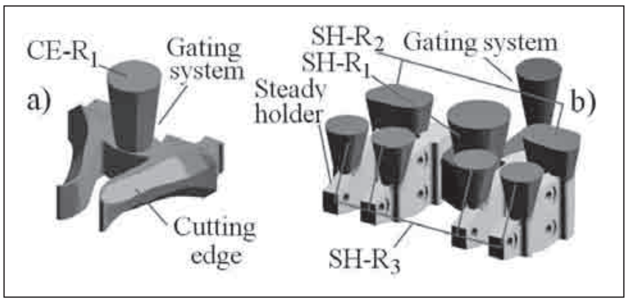

Figure 2 CAD basis elements of MagmaSoft

Such coupled CAD models are then deployed in casting simulation with MAGMASoft [2]. This software package offers rapid and accurate parameter adjustment within a feasible domain of the casting process [3]. Hence potential faults can be easily detected in an early engineering stage. If necessary, appropriate corrections are to be made either in CAD design or in process parameters. Typical 3D rendering in MAGMASoft illustrates the following issues: 1) molten metal flow and cavity filling 2) temperature field and flow speed 3) demarcation zone of solidification, consequently points of possible micro porosity. Besides the 3D CAD model, MAGMASoft requires definition of technological parameters of the casting process. In this particular case the list of casting parameters is as follows:

Table 1 **Casting parameters**

	Cutting edge	Steady holder
Cast material	E295	X120Mn12
Mold material	CO_2, sand	CO_2, sand
Core material	CO_2, sand	/
Casting temp	1 520 °C	1 560 - 1 580 °C
Ladle type	angular	angular
Casting type	gravitational	gravitational

OUTCOME OF THE SIMULATION

Conceptual design of a mold for coupled casting is set in a symmetrical form around central riser for both parts. Considering the casting fundamentals [4,5], and the part design the main riser (*CE-R$_1$*, *SH-R$_1$*) in either case, should be simply placed above the sprue (Figure 2 a, 2 b). However casting simulation recommends introduction of additional risers for steady holder (*SH-R$_2$*, *SH-R$_3$*) at specific points, in order to avoid part porosity.

"*Fill Temp*" option, in the simulation program, reveals temperature distribution during the molten metal pouring (Figure 3 a, 3 b). 3D render shows regular mold filling and temperature field of either of two cavities at 30 % replete. Symmetrical molten metal distribution is kept up to the very end of filling in both cases.

After having both cavities filled, the **"*Solidification*"** option may be activated. Figure (Figure 4 a, 4 b) shows the progression of solidification from the tinniest toward thickest zone, as well confirms that the riser solidifies the last, meanwhile compensating cast body contraction.

"*Fstime*" module shows elapsed time and availability of molten metal from macro-rising at the certain point of solidification. For example at 34 % solidification, cutting edge (Figure 5 a) shows proper solidification progression. Figures (Figure 5 b, c) show steady

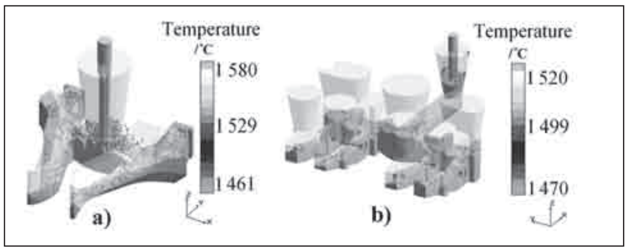

Figure 3 Temperature distribution during the molten metal pouring a) cutting edge b) steady holder

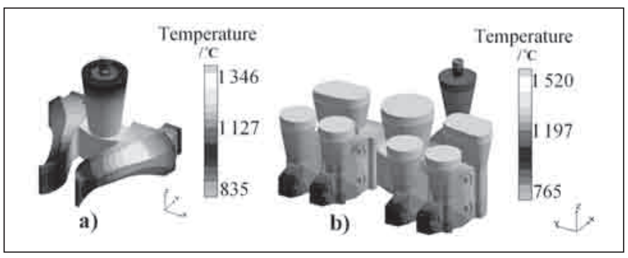

Figure 4 Solidification zones a) cutting edge b) steady holder

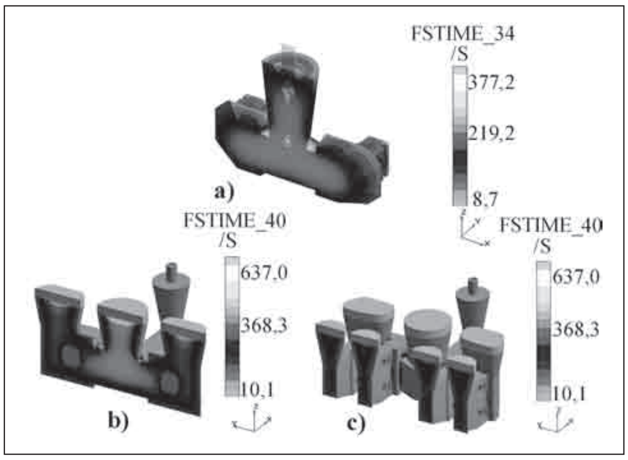

Figure 5 Solidification diagram a) cutting edge b, c) steady holder

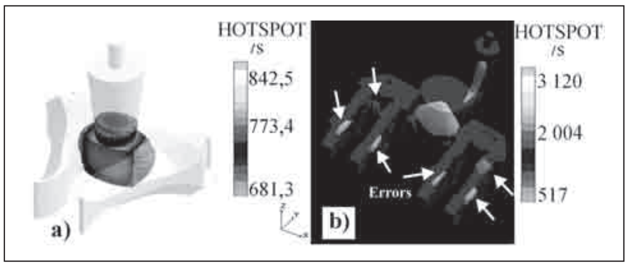

Figure 6 Prominent spots which solidify the last a) cutting edge b) steady holder

holder's cross-sections through risers *SH-R$_1$-R$_2$* and *SH-R$_3$* respectively.

Application of "*Hotspot*" criteria reveals prominent spots which solidify the last (Figure 6 a, 6 b). In case of the cutting edge casting, the hotspot is at the riser location, which is the most preferred point. Unlike the cutting edge, the steady holder (Figure 6 b), when fed through a single riser *SH-R$_1$*, had several hot spots in its body, which are the points of possible fault. Therefore the sets of additional risers are introduced (*SH-R$_2$, R$_3$*).

Another criteria "*Porosity*" enables porosity and internal cavity analysis, as well as an overview of stress distribution in the casting. Figure (Figure 7 a, b) illustrates cutting edge cross-section. Obviously, previous inspection with "*Hotspot*" criteria was correct, and the "*Porosity*" criteria just verifies soundness of the virtual casting.

Regarding the objections got from "*Hotspot*" criteria (Figure 6 b) a significant correction of the steady holder CAD model was conducted. Instead of a single riser (*SH - R$_1$*) two additional sets of risers (*SH - R$_2$, R$_3$*) were positioned in a proximity of the hot spots. In order to experiment with virtual casting, a hypothetical set of risers (*SH-R$_3$*) is placed on just three, out of four critical hot spots (Figure 8 a). The result suits the expectation. At the point of missing riser appears casting fault (Figure 8 b). Figure (Figure 8 c) proves that the full set of risers (*R$_3$*) eliminates possible fault.

CASTING OPERATIONAL VERIFICATION

Process of casting operational verification has two independent routes. Each one deals with the separate coupled part casting: cutting edge and steady holder respectively.

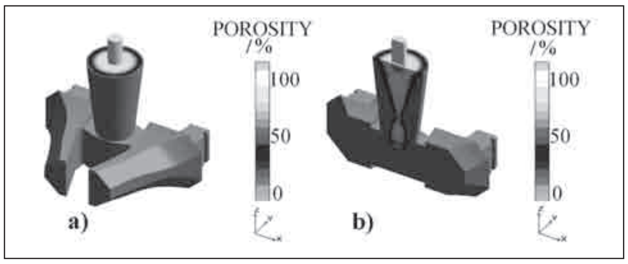

Figure 7 Cutting edge cross-section a) through the top b) through the riser and sprue

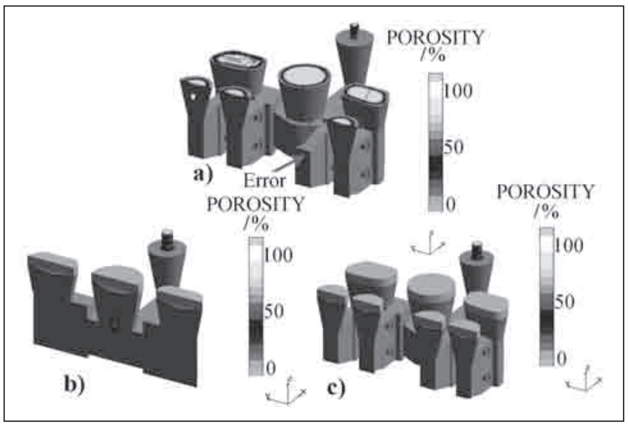

Figure 8 Steady holder porosity a) cross-section through R_3 (three out of four hotspots) b) cross-section through R_1 and R_2 c) cross-section through R_3

Following the CAD model definition, appropriate pattern of the cutting edge is made, and the part is casted in a CO_2 sand mold in conformity with recommended technological parameters. After molding, part is cut along its axis, and the cross-section is expressed in figure (Figure 9 a). Evidently the part is completely without any porosity. Slightly different approach is made in steady holder casting. The pattern and mold are formed in accordance with initial concept illustrated in figure (Figure 6 b). Outcome of this faulty approach is a product with cavities (Figure 9 b, c). In the next step the pattern, likewise the mold, are modified with additional set of risers, copying adequate CAD model (Figure 2 b). After casting the part with such an improved mold, no more inner faults occurred (Figure 9 d, e).

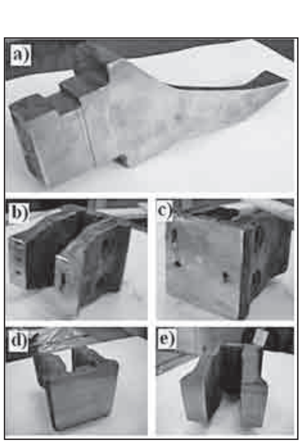

Figure 9 Cross-section of the casting a) cutting edge b,c) steady holder with missing riser d,e) steady holder whit complete set of risers

CONCLUSIONS

MAGMASoft is a modern, powerful software tool, with prominent features in supporting effective and rapid casting design and process definition. MAGMASoft enables optimization of casting features through a virtual trial work instead of expensive and lengthy foundry prototyping. MAGMASoft perfectly simulates a real molding process of the cutting tooth for the bucket wheel excavator. The particular contribution of this specific methodology stands in: 1) adequate process simulation 2) proper use of assessment criteria 3) high degree of compliance with the real casting processes 4) precise indication of critical points (*Hotspot*/*Porosity*).

The strength of the last listed MAGMASoft feature was effectively proved by intentional casting of a part, which was initially recognized as a faulty. Real casting had the same faulty nature as already recognized with the software package. Right after that, the MAGMASoft warnings were applied in pattern modifying, and the outcome was a perfect casting as predicted.

Wider use of this kind of software will certainly accelerate cast parts development. Accordingly, this will cause larger implementation of castings, due to increased performance/cost ratio and drastically improved reliability of these items.

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