Analysis of Volume Changes of Gravitation Sand Casted Magnesium Alloys

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Abstrakt
Práce se zabývá analýzou objemových změn během tuhnutí a chladnutí odlitků z hořčíkových slitin v pískových formách. Jsou zde shrnuty základní teoretické poznatky o problematice tuhnutí a chladnutí odlitku z Mg slitin. Především se práce zabývá analýzou vad souvisejících s objemovými změnami během chladnutí a tuhnutí. Za účelem provedení analýzy vad byl proveden experiment a numerické simulace jako ověření experimentu. Porovnáním výsledků experimentu a numerických simulací vznikly tabulky, které lze chápat jako interpretaci výsledků simulace pro skutečné odlitky. Tuto interpretaci lze využít v praxi při návrhu výroby nových odlitků, tak aby byla stanovena optimální velikost nálitku pro daný odlitek a byl tak vyroben odlitek požadované kvality při co nejnižších nákladech na výrobu.

Klíčová slova
Magnesium alloys, Gravity casting, Feeding, Volume changes

1. Introduction

The knowledge of the volume changes is generally very important in production of castings, because the majority of defects in castings is caused by volume changes during solidification and cooling. These defects include shrinkages, porosity, hot tears, cracks, etc.
For most of the casting alloys there are various empirical formulas and various recommendations for the design of casting, gating system and feeders. For magnesium alloys there is very little data about their behavior during solidification. Because of the specificities of most magnesium alloys such as their low density and wide two-phase zone the empirical formula for aluminum alloy cannot be used for magnesium and empirical formula for magnesium alloy castings mainly doesn't exist.
The aim of this work was summarization of theoretical knowledge of the volume changes in the Mg alloy during cooling and solidification and also designing of an experiment, which was verified by numerical simulation. The experiment was carried out by pouring of test samples with different modules of risers. Then evaluation of internal quality of castings and interpretation Niyama criteria was made.

2. Magnesium alloys solidification

From the results of the experiment we can presume that the magnesium alloys solidify endogenously. This method of solidification corresponds with the final structure of the casting and also with the most common type of defects of castings.
For endogenous solidification it is typical that there isn’t any strong solidification front, but the casting is solidifying in the whole volume. The solidification begins with the creation of crystals which continue to grow. At the end of solidification remains isolated islets of melt. [1, p. 59]

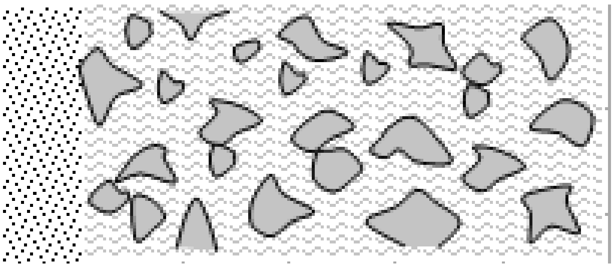

Fig. 1 *Endogenous solidification [1, p. 59]*

Because crystals are growing through the volume of the melt, the feeding is blocked. For this reason in the endogenously solidifying alloys occurs mostly mikroporosity.
Used alloy AZ91 has presumption for endogenous solidifying because it has wide solidification interval. Another reason for endogenous solidification of sand cast AZ91 alloy is inoculation which increases the number of crystallization germs and supports creation of network of crystals in melt. The last reason for endogenous solidification is small temperature gradient in the AZ91 alloy during solidification. We can expect small temperature gradient in the sand cast AZ91 alloy, main reason for this is good heat conductivity of magnesium alloys and low values of heat conductivity of sand molds. Small temperature gradients generally occur in sand molds because of low heat conductivity of the mold.

3. Natural convection

When the bottom gate is used, which is typical for magnesium alloys, the melt becomes cold and from bottom the mold is fed by the melt with higher temperature. After filling of the mold, there is the coldest melt on the top and the hottest melt in the bottom. If the wall thickness is big enough and the heat conductivity of mold low enough, the melt will not solidify immediately and hotter melt with lower density from the bottom begins to flow upward.
Natural convection of magnesium alloys is quite strong. This is caused by large thermal expansion of the melt. At temperature 100 °C over the melting temperature the thermal expansion of liquid phase of magnesium alloys is 7 %. For aluminum alloys is the same thermal expansion only 1,2 %. According this the differences between density of colder and hotter melt will be much bigger for magnesium alloys then for aluminum alloys. So that natural convection will be much more significant for magnesium alloys than for aluminum alloys. Because of natural convection it is possible to reach solidification from bottom to the top even if the bottom gate is used.

4. Design of experiment and its verification by numerical simulation

Since the most serious effect of volume changes during solidification of castings is the formation of defects, the experiment was aimed to explore appearance and spacing of shrinkages and porosity. Due to the position, size and type of defects it is possible to describe the behavior of alloys during solidification. Another aspect of volume changes analyses through the defects is the knowledge of volume changes and its importance for designing suitable technology to manufacture castings with the best possible quality.

For experiment was used alloy AZ91HP composed of 50 % new material and 50 % returns, which is mostly used composition. For making molds it has been selected furane sand with addition of burning inhibitors.

5. Design of test samples

Two types of plate-shaped test samples were designed. First one was plate with thickness of 10 mm and dimensions of 100x200 mm. Second one was plate with thickness of 45 mm and dimensions of 225x450 mm. Thickness of plates was designed the same as walls thickness of most common magnesium sand castings. Dimensions of test samples were selected to be large so that there defects in the samples appear.

To perform the experiment, it was decided that the test samples will have different sizes of risers. Sizes of risers were chosen so that the ratio Mr (risers module) / Mc (casting module) = 1.1, 1.2 and 1.4.

Concerning the characteristic of the AZ91 alloy, which was chosen for the experiment, mainly defects of porosity were expected inside the test samples. Shrinkages can be expected particularly in risers or in larger thermal nodes, which doesn't occur on our test samples.

One of the areas where defects were suspected was riser and the area under riser. The peripheral area of the plate was not suspected to be some defects same as the area nearby riser (so-called the scope risers Ln). Areas where defects can be expected are areas with zero temperature gradient. This area which is so remote from the riser, that the riser is unable to feed the melt and also distant enough from the edge of the plate, so as it isn't affected by heat dissipation from the edge of the plate.

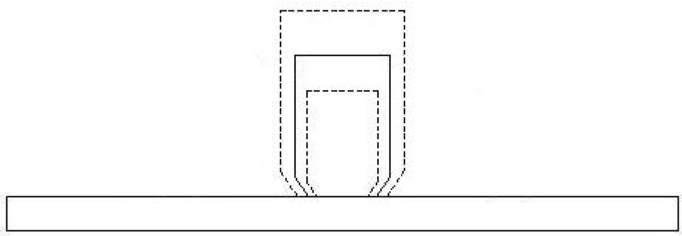

Fig. 2 *Test sample with different sizes of risers*

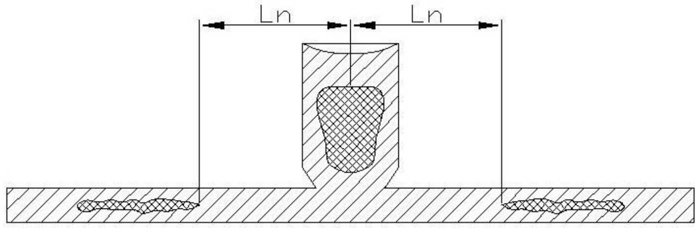

Fig. 4 *Expected defects distribution in the test casting.*

6. Verification of the experiment by numerical simulations

At first the experiment was verified using numerical simulation program NovaFlow. Pouring temperature was set at 760 °C for plate of thickness 10 mm and 720 °C for plate of thickness 45 mm. These temperatures were determined by experience in magnesium alloys foundry. Mold temperature was estimated at 28 °C. Mold material was set to furane sand and cast material was set AZ91.

Simulation results confirmed that only porosity and no shrinkages will appear.

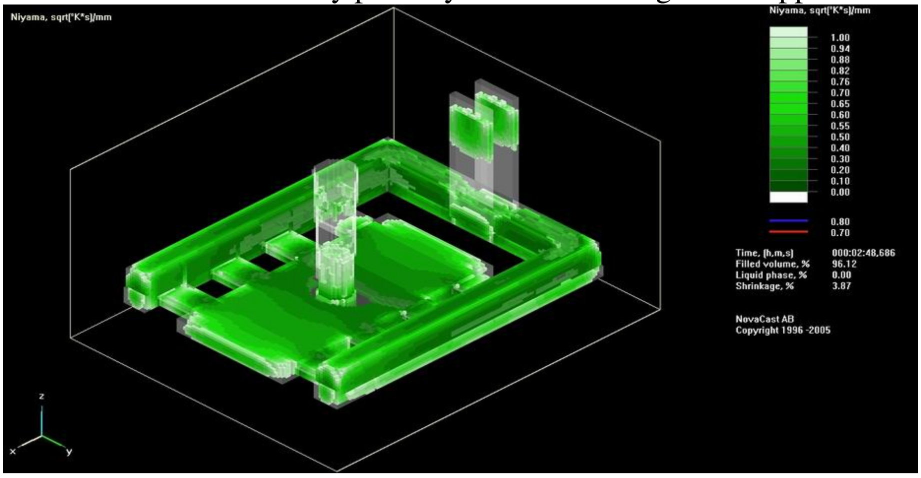

Fig. 5 *Simulation results – Niyama criterion (probability of porosity appearance)*

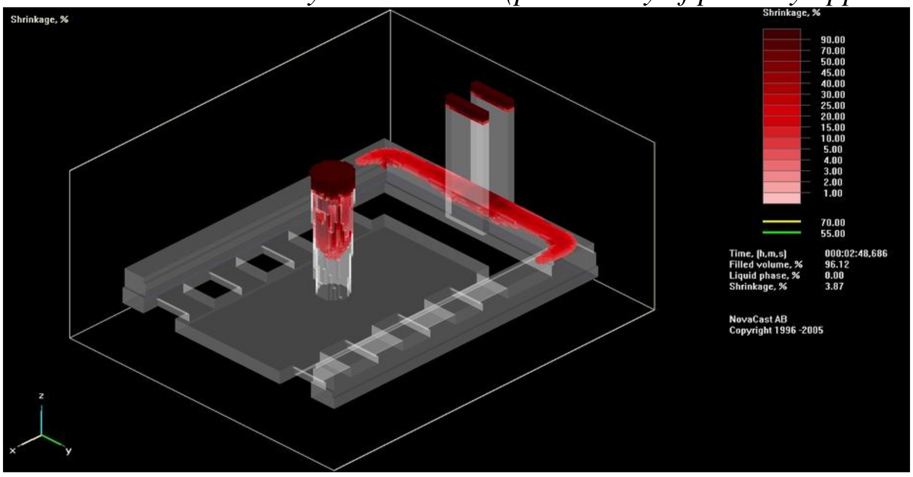

Fig. 6 *Simulation results – appearance of shrinkages*

7. Numerical simulation with data measured during experiment

During the experiment basic data, which are set into the simulation software, was monitored. Mainly temperature of molds, pouring temperature and also final dimensions of risers were checked - especially accurate height of risers. Then new simulations were made. Into these simulations there were entered accurate data measured during experiment. Subsequently the actual defects were compared with results from the simulation program.

8. Evaluation of experiment

As first industrial X-ray scanning was performed. This confirmed that there aren't any shrinkages in the castings. By X-ray it is not possible to precisely determine microporosity which occurred in the castings.

Second test was the measurement of density. For this test the castings were cut to smaller samples and then the density was measured by weighing in water and weighing on air. The progression of density can be explained as progression of internal defects in the casting.

Density curves were plotted on graphs and then 3rd degree polynomial curves were added. Graphs are compared with results from simulations. This comparison shows that the simulation results correspond to reality. This means that where the simulation results showed the largest number of internal defects there was in fact measured the lowest density.
Furthermore metallography and both macroscopic and microscopic photographs were made. It was compared with the simulation results too. From these comparisons a catalog was made. This catalog compares results of simulation with both macroscopic and microscopic photographs. For the microscopic photographs it is marked the accurate location of the defect and also corresponding value of Niyama. This catalog can be used as an interpretation of Niyama criterion for Mg alloys. Comparing the results of simulations and macroscopic photographs is evident the relation between amount of porosity and value of Niyama criterion. From the microscopic photographs can be seen the relation between Niyama criterion and rate of porosity.

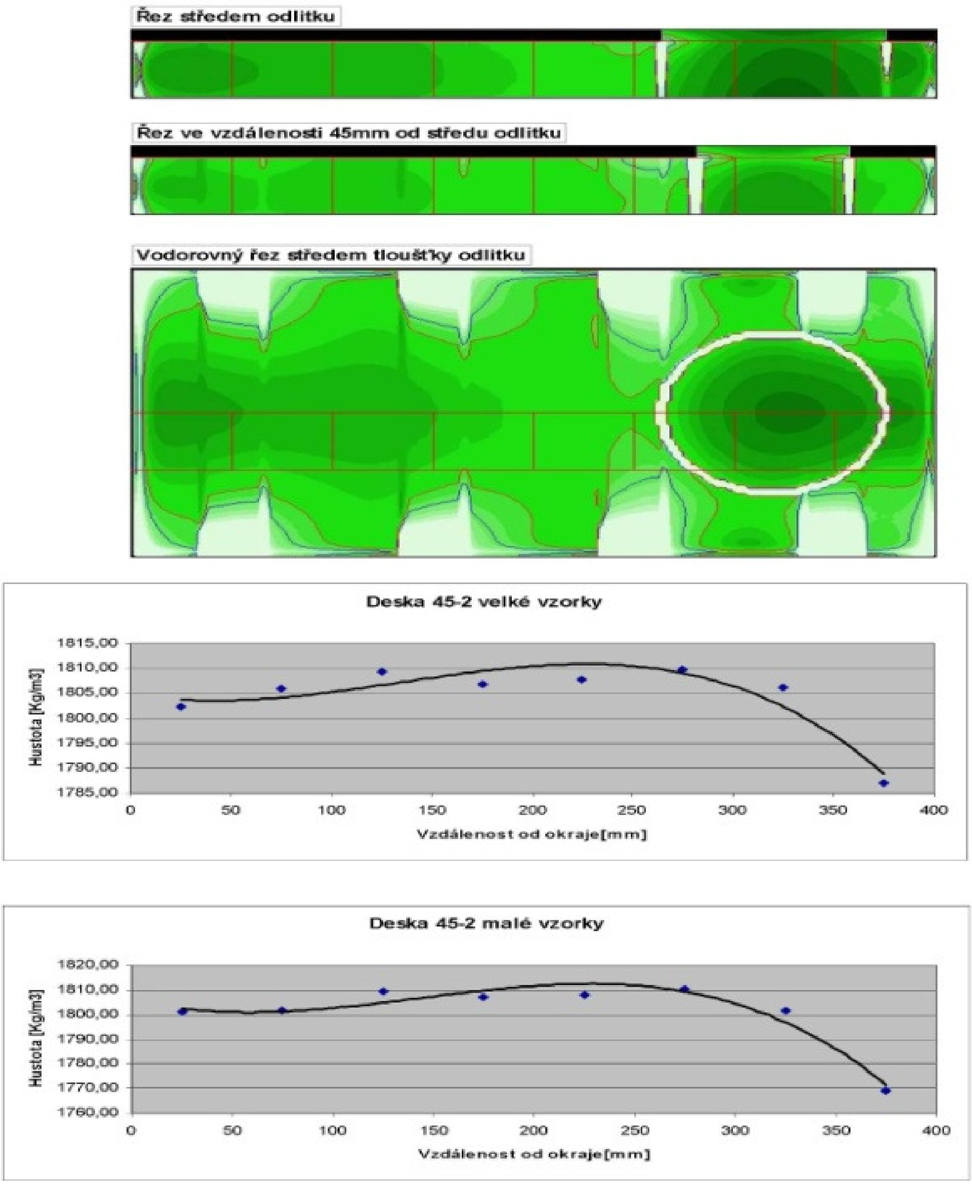

Fig. 7 *Evaluation of experiment – density measurement*

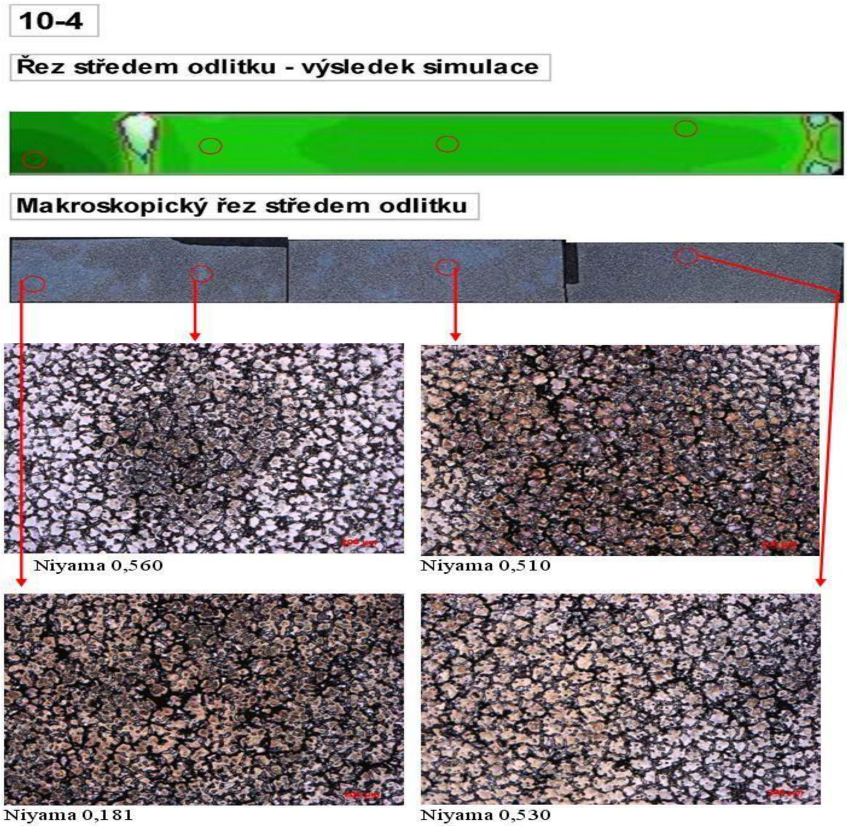

Fig. 8 *Evaluation of experiment –interpretation of Niyama criterion – comparison of simulation results witch real defects in test samples*

9. Conclusion

Mg alloys in terms of volume changes are different from aluminum alloys by large thermal expansion in liquid phase which is 7% when overheated 100 °C above melting temperature. Result of this large thermal expansion in liquid phase is significant natural convention for sand castings. Volume changes during solidification and during cooling of solid phase are similar as volume changes of aluminum alloys. Shrinkage during solidification of magnesium alloys is 4-6 % and the contraction during cooling of solid phase is 1.2 %.

The most useful result for practice is the interpretation of Niyama criterion for magnesium alloys. This was interpreted by comparing of simulation results with real macroscopic and microscopic photographs. From this comparison is evident the relation between Niyama criterion and porosity in real castings. This interpretation can be used for evaluating of simulations results for new castings.

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