Research and Development of Technology for Large – Thin Wall – High Quality Aluminium Castings for Aircraft Industry

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1.0 INTRODUCTION
Investment casting technology is one of the foundry technologies enabling to achieve both very narrow dimensional casting tolerances (so called “net shape technology”) and also very complex casting shapes [1, 2]. The whole concept of the three years research joint project of Fimes,a.s.- aluminium investment casting foundry in Uherske Hradiste and the Brno University of Technology, is focused to development of this technology [3]. The main goal of this research is the implementation of the achieved results into daily Fimes foundry practice and thus to increase the foundry chances to address customers from aircraft, aerospace, defence and similar hi-tech industries [4].

The whole project and therefore also this paper is divided into 7 parts (Chapters 2.1 – 2.7) following the main phases of investment casting technology:

1. “Mother” die (i.e. mould for making wax patterns)
2. Wax pattern
3. Ceramic shell mould
4. Preparation of aluminium melt
5. Pouring technique
6. Filling the ceramic mould cavity by molten metal
7. Finishing operations and monitoring of the whole manufacturing process in the first year of the project (2011) the actual situation at Fimes foundry in each phases of the technology has been analyzed (design of the dies, making wax patterns, pattern assembly including gating systems, monitoring existing shelling process, preparation of the aluminium melt, pouring techniques, etc.) and in each part of the process also direction of future research set up.

2.0 ACHIEVED RESULTS IN THE FIRST YEAR OF THE PROJECT [3]

2.1 “Mother” die (metal mould for making wax patterns)

2.1.1 Tested method of rapid prototyping suitable for foundry
The tested method is combination of FDM technology for making “prototype ABS pattern” – followed by making wax pattern in silicone mould and making final casting by using investment casting (lost wax) technology.
The main objective of this part of the research was to verify the possibility of meeting the specified dimensional tolerances by using the RP technology selected by us (producing the master pattern – making the silicon mould – making the wax pattern) and to compare the achieved accuracies with those achieved by using the conventional
technology (making the metal “mother” mould by machining – making the wax pattern). Moreover, these technologies were compared also from the viewpoint of production rate and economy.

**Evaluation of achieving the dimensional accuracy of wax patterns** It was found out by measuring the dimensional accuracy of wax patterns that tolerances specified in the drawing of a casting can be met by using the production method of wax patterns with the help of the silicon mould and that this technology is satisfactory from the viewpoint of satisfying tolerances specified by the customer. From the viewpoint of the process stability, the values of capability index \( \text{Cp} \) exceeded 1, 33 and met thus the 4 Sigma capability condition. The IT accuracy grades of both dimensions satisfy the customers’ requirements. From the viewpoint of the surface quality, the wax patterns from the silicon master mould achieved the quality that was very similar to the one from the metal master mould.

It can be stated in general that for small series of castings the production of wax patterns using the silicon master mould is a fully satisfactory method both from the dimensional and surface quality viewpoints (Fig.1a, b, and c).

2.1.2 Developed and tested software for simulation of wax filling into “mother” dies.

This unique software should help the designers of “mother” dies to propose the correct gating systems for wax injection to achieve high quality wax patterns “right in the first time”.

The manufacturing of wax patterns for foundry technology of investment casting pattern is one of the key phases of production of perfect casting. The manufacturing of injection mould by machining increases high initial costs. Therefore it is necessary to manufacture the mould correctly for the first attempt, so that it allows the production of wax patterns in desired quality. The quality of the wax pattern is influenced not only by the material, dimensional accuracy, surface of the mould, but also optimal injection set, temperance of the mould and setting of the injection parameters of the injection machine. With the transition of many foundries of exact casting to segment of casting with “high added value” intended to fulfil the high demands of customers, the demands for perfect knowledge of the impacts of all the incoming parameters of the production increase sharply.

One of convenient tools for optimization of the phases of pattern production is also numerical simulation. Numerical simulation of the whole production phase of wax pattern (that is from the filling of the cavity by wax until predication of its shape changes in time after it has been taken out of the mould) is not nowadays at any foundry’s disposal according to available information.

The first results in this area of research were already presented [5, 6], also at the last Conference in Portorož in 2011 [7].

Of course this research is being developed further and the main directions are at the moment oriented basically into four major areas where the needed data are being obtained / precise step by step:

- Material database of injected wax blend
- Initial and boundary conditions of the computation
- Run parameters
Validation of the process of filling the cavity

Here it is necessary to compare the created numerical model of the process of filling the cavity with wax blend with the real process of the cavity filling on injection machine. In the first phase of the validation it was necessary to design a simple injection mould (Fig. 2), which allows quick production of testing wax patterns under different injection conditions. It allows recording the whole process of filling the cavity with a camera recorded. On the basis of attained data the numerical model is adjusted. First achieved results of simulation are in the Fig.3. In the second phase of this research is the model used for more complex mass-produced wax patterns (such as in the Fig.4).

Summary of so far achieved results in simulation area

On the basis of comparison of the real process of filling the cavity of the testing mould on injection machine and prototype simulation it can be said, that sufficient agreement was reached. In the next step it is necessary to apply this prototype simulation on more complexes mass-produces shapes of wax patterns. As it is clear from the so far obtained results, the simulation of the die cavity filling by wax the software ProCast has been tested and is now ready for its further testing in practical use on complex shaped wax patterns (Fig.4). This numerical prediction can be used for the design of gating system of the die, especially from the point of view of its optimal filling. For the future development of the software it is expected that the simulation will not be only used for above mentioned die cavity filling by wax but also for prediction of possible wax patterns defects, such as cold shuts, bubbles, porosity etc. In this technology, which is also called “net-shape” it is very important to have dimensions of the wax patterns under very strict control, for which the simulation software should also be helpful in future.

2.2 Wax pattern

Detail laboratory analysis of several types of waxes suitable for thin wall wax patterns have been done at Blayson (UK) laboratory. The basic physical, rheological and technological properties of different waxes have been tested and the best versions recommended for its use at Fimes foundry. Some examples of results can be seen in Fig.5, and 6. Based on the achieved results the optimal combination of pattern and runner waxes are now being tested in semi-production scale.

2.3 Ceramic shell mould

Detail laboratory analysis of several types of so far at Fimes used ceramic shell compositions have been done at the CARRD laboratory of IMERYS (A). Examples of tests are in Fig. 7 and 8. Based on these results the optimal ceramic shell composition has been suggested (i.e. compositions of slurries and also stuccos for both primary and back up coats). These are now being tested in semi-production scale and the best version will be introduced into full production in late 2012.

2.4 Preparation of aluminium melts
2.4.1 **Detail analysis of all technological operations** connected with preparation of the melt for pouring has been done, i.e. purification, modification, grain refining and degassing. Also analysis of on-line checking of the melt quality has been analyzed with the aim of introducing it into the Fimes production.

2.4.2 **Analysis of incoming raw materials for the aluminium melt** has been also done at the independent metallographic laboratory of State Research Institute (CZ) and the achieved results compared with the results of Fimes laboratory.

2.5 **Pouring technique**

In this part of the research the basic measurements of temperature fields of the system “ceramic mould – aluminium alloy” have been done (Fig.9). The main purpose of these experiments was to determine basic conditions for ideal pouring system taking into account especially behavior of the molten aluminium being cast into ceramic shell mould both under air and vacuum conditions. During these tests an especially design test for measuring of metal fluidity (i.e. ability of the molten metal to fulfill the mould cavity) has been used (Fig. 10). Also influence of possible metal filtration has been tested during these experiments.

2.6 **Filling the ceramic mould cavity by molten metal**

These investigations are very closely connected with previous measurements. Following to these first results also testing of special “cage gating systems” for larger castings (up to 700 mm length) have been done. All designs of these special gating systems have been proposed based on the results achieved by simulation of both filling mould cavities by molten Al alloy and also its solidification.

2.7 **Finishing operations**

This part of the research is covering the monitoring of the whole process at the foundry which in the end should achieve the NADCAP certification (aircraft and aerospace level). To complete the whole process (which was not covered by previous parts of the research) this research is also focused to the removal of ceramic from the final casting, heat treatment of the casting and final testing methods for checking the final casting quality (both destructive and non-destructive methods).

3.0 **CONCLUSIONS**

The main goals set for the first year of the project, (i.e. to investigate existing situation at the foundry and to find out relevant solutions) have been fulfilled. By detail analysis of the actual situation at the foundry many new findings and also topics for further investigations have been discovered, which will be taken into account when setting new updated goals for next project phases.

NOTE:
As it is quite clear from the above short description of the project goals and the first findings this research is very broadly oriented and as a such require very demanding coordinating and monitoring system for controlling of all activities being done both at the Fimes foundry and at the Brno University of Technology. As a very helpful in this
respect was in the Project Year 1 found the system Basecamp on internet, used successfully by the project participants.

REFERENCES


Acknowledgments
The presented paper is one of the main outputs of the TA 01010766 Project „Research and Development of Technology for Large – Thin Wall – High Quality Aluminium Castings for Aircraft Industry“ financed by the Technology Agency of the Czech Republic.
FEW FACTS ABOUT MILAN HORACEK
Married, 2 sons (Martin 38 + Lukáš 30)

Education background

- BUT, Faculty of Mechanical Engineering/Foundry Dept. – 1967-1972
- PhD studies at BUT – 1973-1976 – finished by defending the thesis on topic:
  “Influence of degree of metal flow on the course of solidification of grey iron”
- Postgraduate studies of English at Charles University in Prague – 1983-85

Positions at BUT
Assistant professor at the Dept of Foundry Engineering – 1976-1983
Associate professor (senior lecturer/docent) – since 1983

Lecturing activities
Several courses mostly in foundry technology at the BUT for bachelor, master and PhD levels. Author of 8 student texts. Every year 2-4 diploma students (total about 90 since 1976).

Research Activities
Thermal properties of sand mixtures (1970-1974)
Crystallisation of grey iron (1974-75)
Solidification of hot spots in castings (1975-78)
Ceramic shells for directional solidification technology (1977-79)
Study of metal solidification in ceramic shells (1978-81)
Gating systems calculation (simulation, software creation) (1983-90)
Filtration of melts in ceramic shells (1986-90)
Production control in investment casting foundry (1991-93)
Accuracy of investment castings (since 1995)
RP methods in combination with investment casting technology (since 2005)

Publications
Total about 120 articles in journals, conference proceedings, etc.

International Projects
Tempus Phoenix 1990-1993 – marketing, finance and management (UK, Italy)
Qualicast 1994-1995 – for TQM in manufacturing (UK, Portugal)
Ovotrain Leonardo project -2006-07 – for creating 7 languages dictionary in metallurgy

Activities in Foundry Societies and Associations

Czech Foundrymen Society – vice president since 1994
(main organiser of the Foundry Days (from 29th FD in 1991 till 47th FD in 2010) +
World Technical Forum in 2009)