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# Development and manufacturing of casting technology for crawler vehicle suspension used in wetlands

*Marcin Małysza[1], Piotr Kowalski[1], Krzysztof Wańczyk[1], Andrzej Gil[1], Sebastian Dziedzic[1], Robert Żuczek[1]*

*[1]Foundry Research Institute, ul. Zakopiańska 73, 30-418 Krakow, Poland*

*E-mail: marcin.małysza@iod.krakow.pl*

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### Abstract

*The modern designing techniques and development procedures requires the use of advanced integrated methods. That kind of approach requires the involvement of series of steps which leads to the logical work stream known as Integrated Computational Material Engineering. The steps involve the design and evaluation process in the virtual environment of CAD/CAE and simulation software. The use of simulation software allows for online optimization of the shape and properties of designed part. The publication presents a design and manufacturing process of a component of the larger assembly of the chassis of heavy-duty machine. Established methodology includes the analysis of the initial geometry of the part of the heavy vehicle used in difficult wetland environmental conditions.*

*Keywords: CAx, computer simulations, Flow3D, Ansys, casting technology, 3D printing, aluminum casting*

## 1. Introduction

The use of CAD/CAE and simulation software allows for optimization of the shape of the part based on the results of exploitation and manufacturing conditions. The part which is the subject of the presented research work is one element of large heavy-duty machine used in difficult wetland environmental conditions. The concept of the vehicle along with the selected part is presented in the Figure 1. The methodology of the conducted design and optimization work is based on earlier presented publication regarding the swing arm for presented vehicle [1].

The integrated methodology of design and development allows for lowering the necessary trials to minimum [2,3,4]. The manufacturing of the prototype vehicle required 400 pieces of the guiding bumpers.

## 2. Design and development methodology

The main purpose of the designed part is proper driving of the drive wheel. Because of that, the part was evaluated in the simulated exploitation conditions in the ANSYS software. The load schematic of the part is presented in the Figure 2.

The boundary condition setup includes the force and mountings of the element with three bolts. Based on several successive iterations of the design and the strength verification, the final casting was developed to transfer

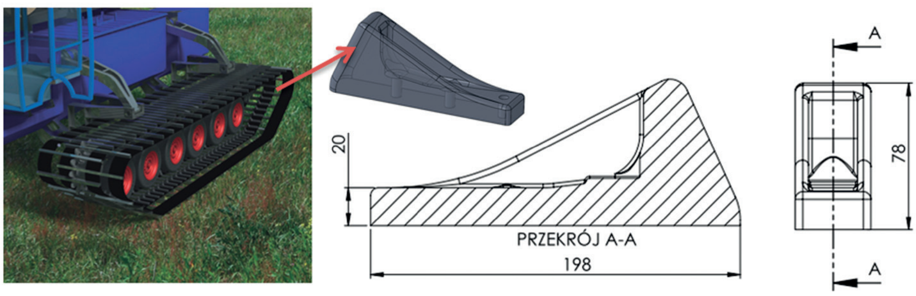


*Fig. 1. Prototype track for heavy-duty machine and the track element – the guiding bumper*

assumed force during exploitation. The visualization of the results is presented in the Figure 3.

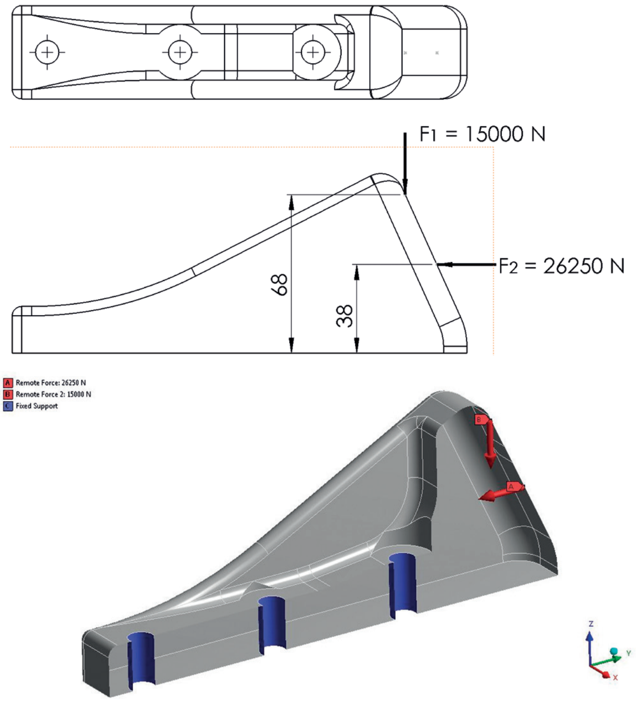


*Fig. 2. Presentation of the direction and value of the force in the load schematic*

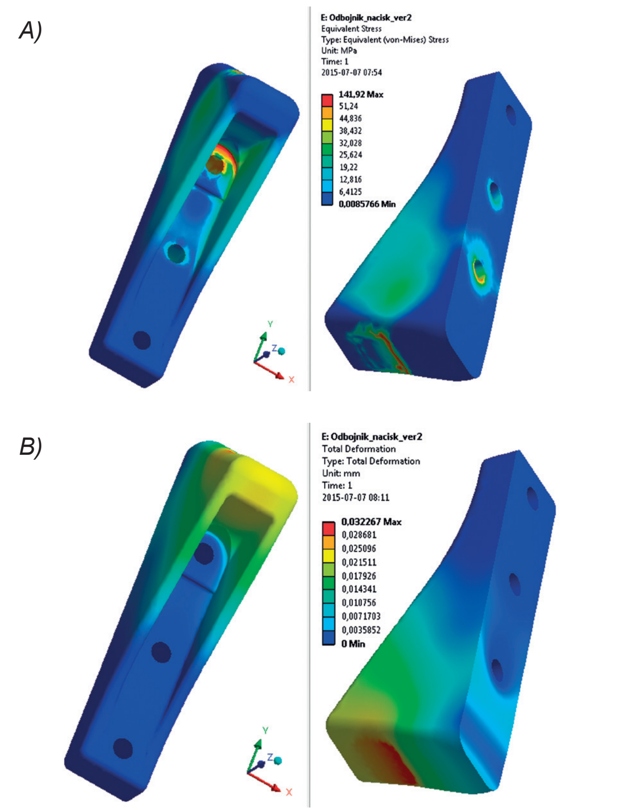


*Fig. 3. Results of the exploitation analysis: A) stress analysis, B) deformation analysis*

The specified value of the maximum stress fields are mainly in the contact at the point of application of the load force which comes from the wheel. The intensity of the force and deformation should not lead to the destruction of the guide bumper construction. A more detailed analysis of the distribution of normal stress fields operating along the principal axis of the model has not shown the areas of strong stresses of compressive and tensile stresses that are the initiator of the material cracking process. The normal stress distributions obtained for the analyzed load schematic of the guide bumper are shown in the Figure 4. The non-uniform scale is used due to the minimal and maximal values occurring in the stress field.

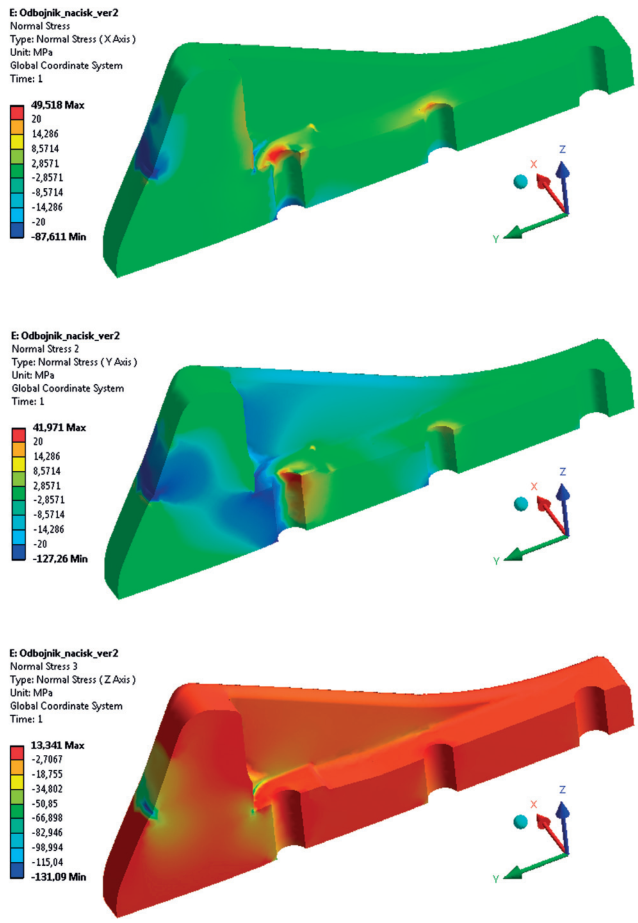


*Fig. 4. Distribution of normal stress fields acting along the X, Y and Z axis*

## 3. Simulation analysis of the manufacturing process

The FLOW-3D simulation software was used for the evaluation of the filling and solidification process. The software uses the technique based on the Volume-of-Fluid (VOF) technique. It has distinctive properties allowing for accurate simulation of free surface flow. The fluid equation are considering the Navier-Stock equations [5,6]:

$$\frac{\partial u}{\partial t}+\frac{1}{V}(Au\cdot\nabla)\cdot u=-\frac{1}{\rho}\nabla p+\frac{1}{\rho V}(\nabla A)\cdot(\mu\nabla)u+g \tag{1}$$

$$\frac{\partial H}{\partial t}+\frac{1}{V}(Au\cdot\nabla)\cdot H=\frac{1}{\rho V}(\nabla A)\cdot(k\nabla T) \tag{2}$$

where:

$$Au=(A_x u_x, A_y u_y, A_z u_z), (\nabla A)=(\frac{\partial}{\partial_x}A_x, \frac{\partial}{\partial_y}A_y, \frac{\partial}{\partial_z}A_z),$$

$$H=\int C(T)dT+(1-f_s)\cdot L$$

$A$ – open space and ($x$, $y$, $z$) direction of flow,

$V$ – open volume fraction,

$\rho$ – density, kg · m$^{-3}$

$p$ – pressure, Pa

$u$ – velocity component,

$\mu$ – dynamic viscosity, Pa · s

$g$ – gravity component, m · s$^{-2}$

$H$ – enthalpy, J · mol$^{-1}$

$T$ – initial temperature of the liquid metal, °C

$f_s$ – solid fraction,

$L$ – latent heat, J · kg$^{-1}$

$C$ – specific heat, J · kg$^{-1}$ · K$^{-1}$

$k$ – thermal conductivity, W · m$^{-1}$ · K$^{-1}$.

$$\frac{\partial T_m}{\partial t}=\frac{1}{\rho C_m V_c}(\nabla A_c)\cdot(k_m\nabla T_m) \tag{3}$$

Equation 3 includes material properties $m$ mould material and reaction between liquid metal and mould surface – Equation 4. The value of heat flux $q$ from the liquid metal is based in the:

$$q=h\cdot(T-T_m) \tag{4}$$

where:

$h$ is defined as the heat transfer coefficient value.

Simulation setup includes the alloy properties of A356 and the material properties of mould material. The material properties are used in the form of temperature dependency. The curves are presented in the Figure 5.

The initial temperature, $T_{in}$ = 680°C and pouring time $t$ = 2 s. The total amount of poured metal to the presented assembly is approximately $m$ = 3 kg. The geometry used in the simulation process is presented in the Figure 6.

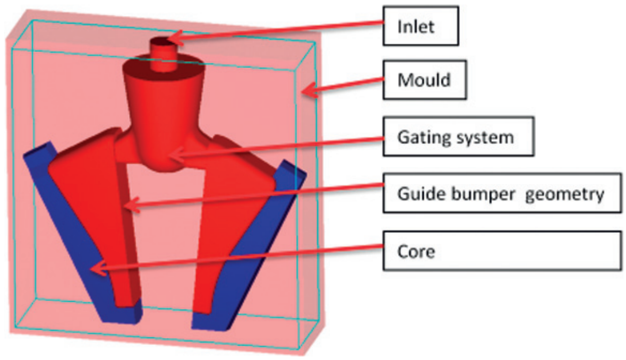


*Fig. 6. The geometry used in the simulation analysis*

The simulation results are presented in the form of visualized flow characteristics. In the Figure 7 the temperature distribution and the flow direction in the cross-section in the mould cavity are presented.

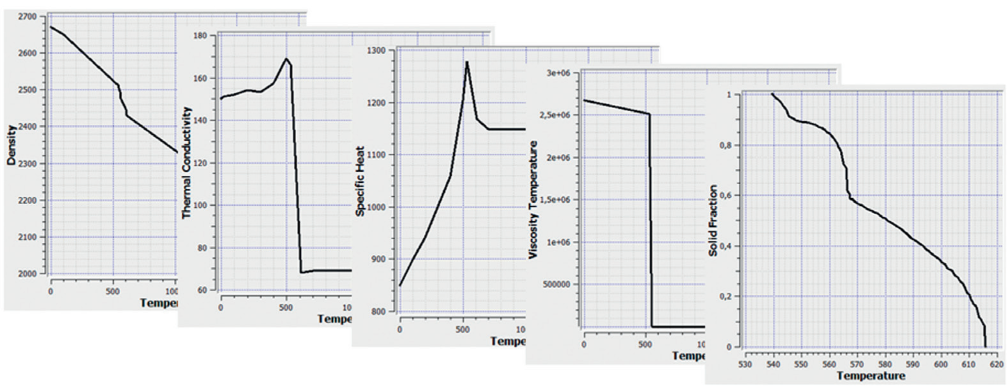


*Fig. 5. Temperature dependency values of material properties*

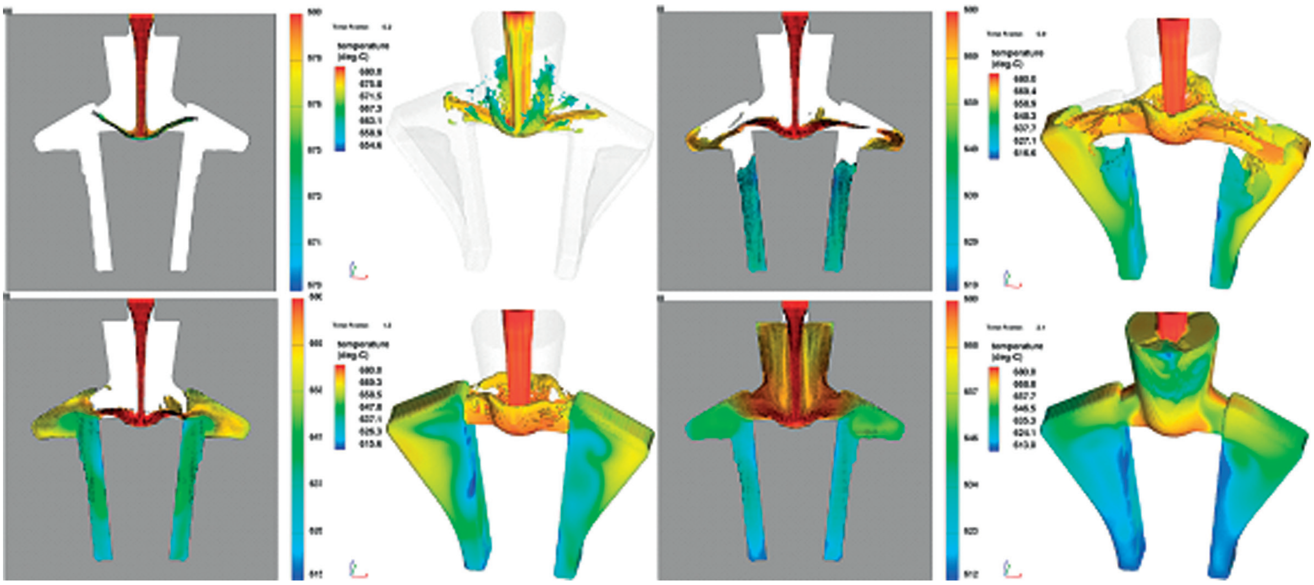

*Fig. 7. Temperature distribution during filling and flow direction in the cross-section view*

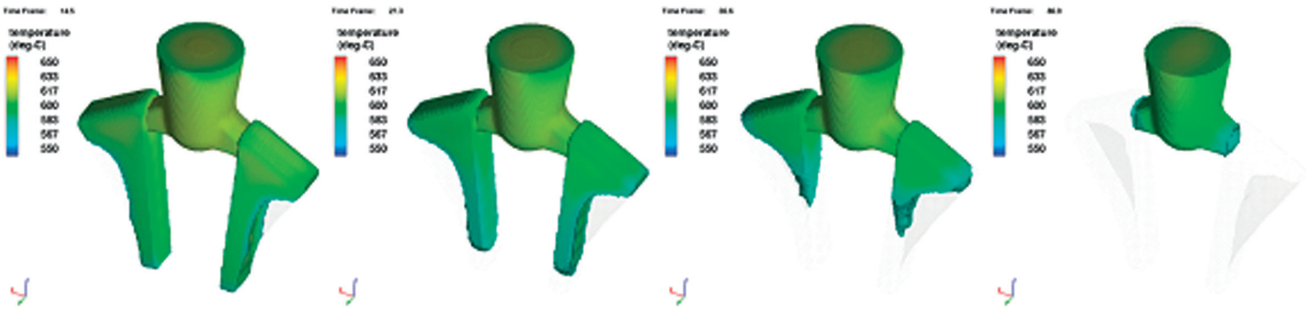

*Fig. 8. Solidification path of the liquid metal*

The casting technology is deigned to achieve the proper filling pattern. Presented visualization shows that the liquid metal at the beginning is splashing when hitting the bottom of gating. During the filling process liquid metal falls down to the bottom of the casting cavity and rising towards the top of the mould cavity. There is no significant vortexes or dissipation of the liquid metal stream. The results of the solidification are presented in the Figure 8.

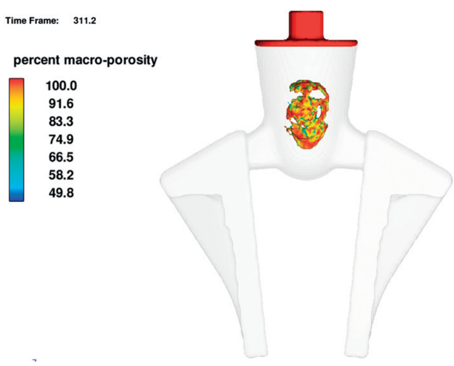


*Fig. 9. Predicted porosities in the casting*

The solidification of the liquid metal in the mould cavity is directional. The presented results shows that the solidification path is forced towards feeder where the hot spot is located. The prediction of porosities is presented in the Figure 9.

The localization and size of hot spot force the shrinkage porosity to create in the feeder. This is the main reason of the designed shape.

## 4. Manufacturing process

For the prototype batch production the 3D printing technique was used. The tooling was manufactured in ABS material in the FDM Titan machine. The plate pattern of the model was printed in approximately 6 h and one half of the core box was printed in approximately 2 h. The printed elements are presented in the Figure 10.

The plate and core box was used to prepare the mould and core from the sand with resin bonded with $CO_2$. The charge material melted in the resistance furnace was nearly 100 kg. Since the one assembly requires 3 kg

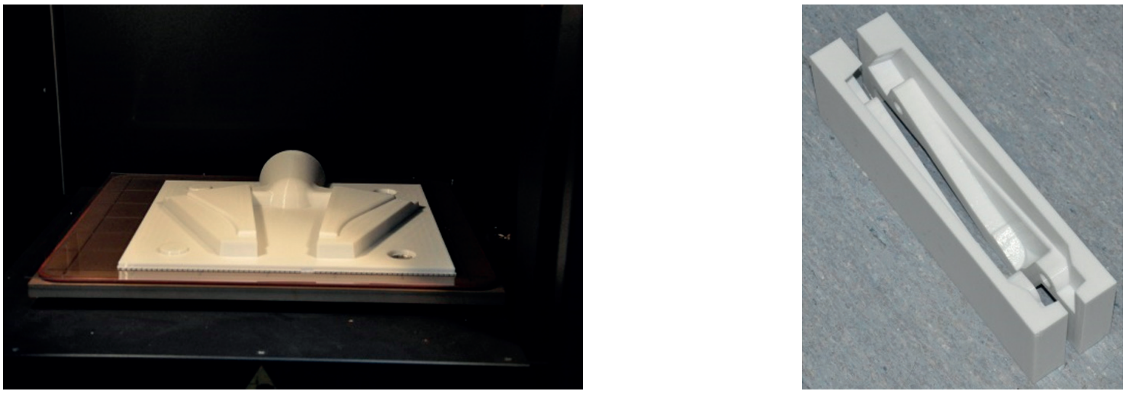

*Fig. 10. Printed plate pattern and core box*

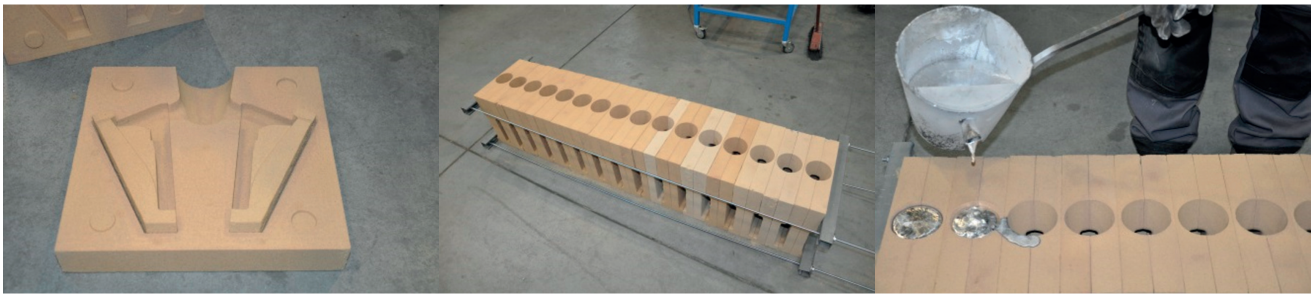

*Fig. 11. Preparation of the casting and filling of liquid metal to the moulds*

*Fig. 12. Final demonstrator with all mounted parts*

of liquid metal moulds was prepared in bath production which is presented in the Figure 11.

The casting after removing of gating system was subjected to the T6 heat treatment involving quenching and ageing. After that the casting was machined, painted and mounted on the track of the vehicle. The final demonstrator of the vehicle is presented in the Figure 12.

## 5. Conclusions

The use of modern techniques and integration of different numerical analysis allows for preparation of complete manufacturing technology. This approach allows for verification of technological guidelines on every step of design procedures. The use of all tools allows for acquiring a good quality casting which meets the actual application requirements.

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