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Development and optimization of casting technology on part of the suspension of a heavy vehicle used in difficult environmental wetland conditions

Opracowanie oraz optymalizacja konstrukcji odlewu wahacza maszyny ciężkiej pracującej w trudnych warunkach środowiska wodno-błotnego

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Abstract

The development of a new element is a very complex procedure requiring a combination of many factors related to the design and manufacture phases. The most efficient way is to use computer simulation which allows for verification of the whole design and production process. Over the years, the development of computer technologies has allowed for the development of an Integrated Computational Material Engineering (ICME). This method in logical sequence makes it possible to integrate the project activities, to develop new manufacturing methods, to select suitable materials and to verify the final process. Such multi-threaded operations significantly shorten the time required for the production of the prototype which speeds up the implementation of the planned production of the designed casting. The additional advantage of such work is the possibility of ongoing monitoring of the changes and their impact on the final product.

Keywords: *ICME, simulation, aluminum alloy, rapid prototyping, casting optimization*

Streszczenie

Opracowanie nowej konstrukcji jest bardzo skomplikowaną procedurą wymagającą połączenia wielu zazębiających się kroków projektowych połączonych z przesłankami technologicznymi wybranej metody wytwarzania. Obowiązujące trendy projektowania uwzględniają wykorzystanie symulacji komputerowej, która znajduje zastosowanie w ocenie założeń konstrukcyjnych oraz analizę numeryczną zjawisk występujących w trakcie wytwarzania. Wieloletni rozwój takiego podejścia pozwolił na stworzenie zintegrowanego systemu projektowania z ang. Integrated Computational Material Engineering (ICME)*. Ogólna charakterystyka metody polega na utworzeniu logicznego ciągu przyczynowo-skutkowego projektowania, doboru materiału i weryfikacji procesu wykonywania oraz eksploatacji. Takie wielowątkowe podejście pozwala na znaczące skrócenie czasu wymaganego do przygotowania produkcji funkcjonalnego prototypu, a następnie wprowadzenie go do testów przemysłowych. Niewątpliwą zaletą jest możliwość ciągłego monitorowania zmian konstrukcyjnych i technologicznych oraz ich wpływ na efekt końcowy produktu.*

Słowa kluczowe: *zintegrowane projektowanie (ICME), symulacja komputerowa, stopy aluminium, szybkie prototypowanie, optymalizacja odlewu*

1. Introduction

Modern techniques for the production of prototype castings include advanced design technologies. The design process must be considered as a logical chain of events. Using computer aided design, manufacturing and computer simulation supports that process. Such a solution allows to take into consideration a number of risks associated with the manufacturing process of the prototype casting part [1,2,3]. Established methodology includes the optimization of the initial geometry of the swing arm of the heavy vehicle used in difficult wetland environmental conditions. The prototype vehicle with the highlighted casting of the swing arm is presented in Figure 1.

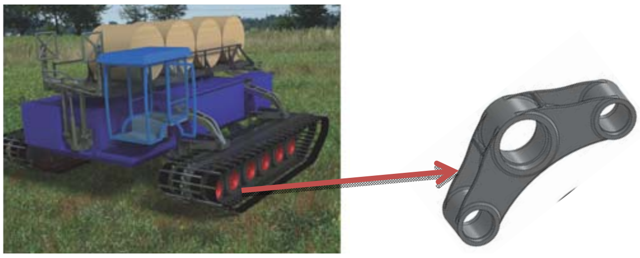


Fig. 1. Prototype vehicle and the swing arm

Rys. 1. Koncepcja projektowa pojazdu oraz projektowany wahacz

2. Shape optimization

The optimization procedure is based on the strength criterion and the properties of the selected casting alloy. The use of the ICME methodology [4] utilises a tool to shape design based on the numerical analysis of exploitation conditions and properties of used cast materials and integrate the results in an essential form. The ICME approach allows reducing the time needed in development and application of a new designed component. Additional savings are achieved for example in the field of conceptual design, material selection and qualification, component design, manufacturing process selection, development and optimization, and process verification. The Figure 2 presents the external shape of the swing arm during the optimization procedure.

Fig. 2. Optimization steps of the design changes of the swing arm shape

Rys. 2. Kolejne kroki optymalizacji kształtu wahacza

The optimization procedure is based on the strength criterion and the properties of the selected casting alloy [5]. Considering the load schematics representing the exploitation conditions, certain nodes exposed to the formation of high stress were optimized [6]. The simulation conditions assume that the weight of the vehicle is m = 6000 kg and for one arm constitutes 1/6 of the total weight. The dynamic surplus ratio is on the level of k = 1.3. For the initial design, static impact of external forces is transferred by the fixed pipe to the wheels and powertrain. The example of load schematic for one of the optimized shapes is shown in Figure 3.

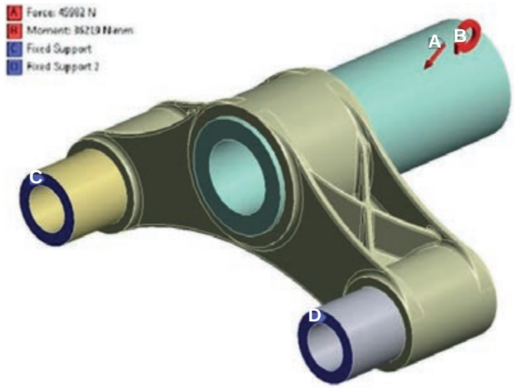


Fig. 3. The load schematic used in the exploitation simulation with the force – A ≈ 4600 N, moment – B ≈ 36 000 N·mm and two fix points C, D

Rys. 3. Uproszczony schemat obciążenia wykorzystany w trakcie analizy eksploatacyjnej, siła A – A ≈ 4600 N, moment – B ≈ 36 000 N·mm, utwierdzenie C, D

The stress analysis conducted in the ANSYS software allows one to visualize the result in the form of stress fields in the construction. In Figure 4 the first analysis of the initial design is presented.

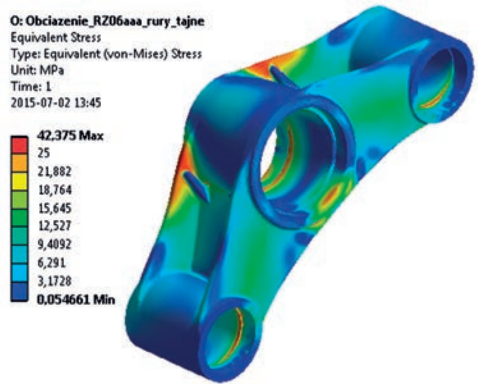


Fig. 4. Stress distribution in the swing arm during the exploitation simulation

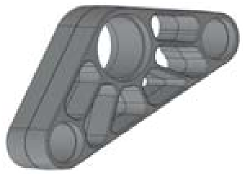
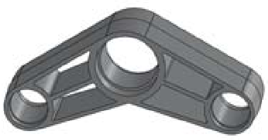
Rys. 4. Rozkład pola naprężeń w przykładowym kształcie wahacza w trakcie symulacji eksploatacji

The analysis of the normal stress distribution in the swing arm construction shows that occuring gradients of compressive and tensile stresses significantly exceed the maximal value. The next steps of structural optimization were performed to achieve a structure that will allow carrying the assumed load in exploitation conditions. Additionally, optimization will allow for designing a economically reasonable manufacturing technology for prototype castings as well as minimizing necessary machining. In Table 1 the results for different versions are gathered.

The strongest stress concentrations are located on the side surfaces near the crossing on the vertical walls and the central ring of the optimized design. The localized stress values do not exceed 40 MPa. In the original version of the element, occurring stress is in the range of the critical nodes approximately 50 MPa. As a result of the optimization process, the virtual – final casting weight will decrease by 15% compared to the initial design. The criterion which was used in the selection of the casting material was based on the safety factor for assumed exploitation conditions and the material strength index. The comparison analysis was conducted for the material A201, A355, A356 and ENAC-43300 which was chosen as the best suitable material. In Figure 5 the estimated safety factor in the final design of the swing arm is presented.

Table 1. Compared results of numerical analysis for different shapes of swing arm

Tabela 1. Porównanie kolejnych kształtów konstrukcji wahacza

Version/Wersja	Maximal Equivalent Stress, MPa / Naprężenia maksymalne, MPa	Total deformation, mm / Odkształcenia maksymalne, mm	Mass, kg / Masa, kg
	45.6	0.21	48.3
	102.5	0.53	40.04
	60.4	0.46	39.47
	66.6	0.48	33.05
	86.3	0.42	39.29
	45.6	0.46	45.62
	42.3	0.31	41

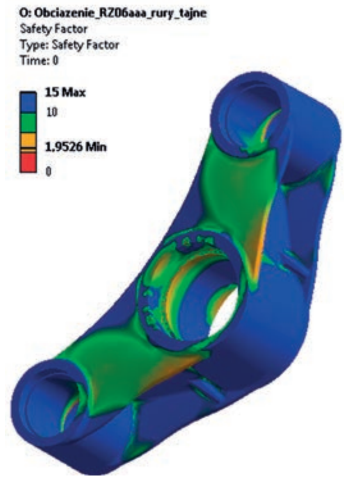


Fig. 5. Distribution of the safet factor in the final desingn of the rocker arm for the chosen material

Rys. 5. Rozkład współczynnika bezpieczeństwa dla końcowego kształtu wahacza

3. Development of the casting technology

The optimized geometrical shape of the swing arm was used in the computer simulation of the casting process. With the addition of the necessary technological treatments which includes machining allowances, wall and ribs tilting. The first step is the numerical analysis of the natural solidification process for the determination of the solidification path for the designed part. The Figure 6 presents the location of the areas which solidifies last. During the design process of the casting technology the efficient feeding in that area needed to be maintained.

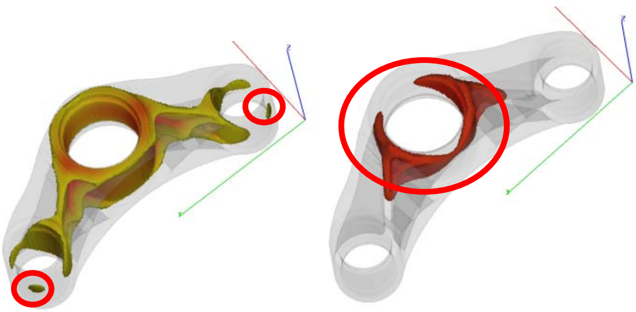


Fig. 6. The natural solidification in the casting geometry with highlighted hot spots

Rys. 6. Analiza procesu naturalnego krzepnięcia z wyszczególnieniem węzłów cieplnych

The casting technology includes different variations of gating and feeding systems for the casting. The Figure 7 presents the different concepts of casting setups. The simulation of the casting technology helped to develop optimized technology to achieve casting with good quality, dimensional accuracy and final properties of the swing arm.

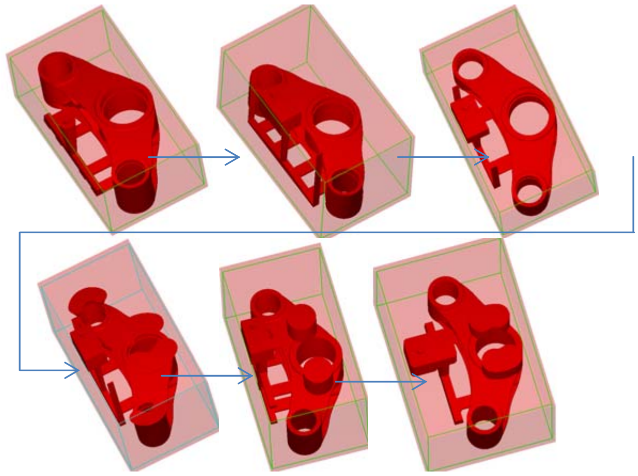


Fig. 7. Concepts of the casting technologies

Fig. 7. Kolejne koncepcje technologii odlewania wahacza

Boundary conditions of the simulation were chosen to be close to the real conditions that occurs in a real casting process, which involves viscousity, surface tension, heat transfer for liquid metal and mold, air entrainment and defect tracking, density evaluation and solidification of liqiud metal in the cavity. The visualisation of filling process is presented in Figure 8.

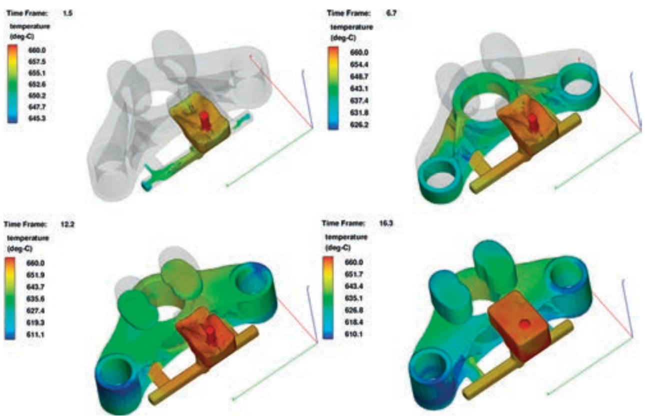


Fig. 8. Visualisation of the filling process

Rys. 8. Wizualizacja wyników procesu wypełniania wnęki formy podczas wirtualnego eksperymentu

The filling time for the casting technology is approximetely t = 17 s. The chosen alloy is ENAC-43300 with a pouring temperature T = 660ºC and mould material binded with CO_2. The final result of the porosity distribution is presented in Figure 9.

The simulation shows that the porosities are located in the riser and gating system. The casting with the proposed technology and casting conditions should affect the sound casting. In order to increase the probability of manufacturing good quality casting the analysis was conducted in additional simulation software – MAGMAsoft. The boundary conditions set up are similar to Flow3D simulation software.

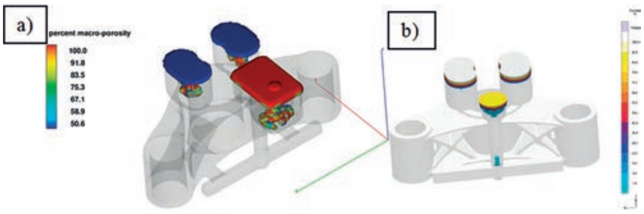


Fig. 9. Predicted porosities in the casting results in a) Flow3D, b) MAGMAsoft

Rys. 9. Prognozowane porowatości na podstawie wyników symulacji w odlewie uzyskanych w programach a) Flow3D, b) MAGMAsoft

Based on the technology all casting tooling was designed to be manufactured in the rapid prototyping FDM technique. The melting was performed in the resistant furnace. During the melting procedure the quality samples were taken to perform the optical spectrometry analysis. The pouring procedure and the final casting are presented in Figure 10.

a)

b)

Fig. 10. Pouring of the liquid metal (a) and the final casting (b)

Rys. 10. Proces odlewania ciekłego metalu do formy (a) oraz gotowy odlew (b)

The casting after machinig, painting and ready for shipment is presented in Figure 11.

Fig. 11. Final swing arm casting

Rys. 11. Odlew wahacza po przeprowadzonej obróbce mechanicznej

4. Conclusions

1. The use of computer optimization for geometrical purposes lowers stress levels occurring in the nodes of the element and reduces the weight.
2. The computer simulation of the casting process allows designing appropriate casting technology, which can be used in the rapid prototyping of casting tooling.
3. The use of computer simulation in a logical sequence allows for quick and accurate design of prototype casting.

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