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The use of icme process to design a rocker arm for special-purpose vehicles

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Summary. The conversion of elements from welded part to casting, using advanced foundry alloys gives a possibility to improve properties of newly designed construction. Application of computer techniques CAD/CAE allows to integrate the work of designers, constructors, foundrymen in one production process called ICME. In order to reduce the weight of particular suspension elements and rise of the dimensions tolerance, the high strength AlZnMgCu alloy was used on rocker arm cast. The design of the new rocker arm was based on the real steel element, complete computer analysis of exploitation environment was performed; additionally the casting technology was verified in order to produce a lower rocker arm of a special-purpose vehicle.

Key words: numerical simulation, high strength aluminum castings, material and design conversion, suspension of mobile vehicles.

INTRODUCTION

Reducing the weight of the structure while maintaining its original functionality, or decreasing the expected maximum values of stress fields operating in individual sections of the structure contributes significantly to improved performance properties of the selected item [1,2]. The conversion of structure or of both the structure and material requires the use of most advanced materials and modern manufacturing technology, as well as close cooperation between the designer and process engineer. The world trends are aimed at significant reduction in workload of performance parts, e.g. by replacement of parts welded or bolted with monolithic cast structures. The development of modern casting technology and new alloys with improved properties significantly contribute to more vivid interest in the cast structures. The use of better and better computational models enables an integration of the materials science with the design process and making a new structure (ICME – Integrated Computational Materials Engineering) [3-7]. This provides great advantages, including shortening of the design and lead time to get a new product through a comprehensive analysis of numerous variants of the solution without the need for a costly and energy-intensive research conducted on real models.

This article presents only a part of the research using an integrated calculation process for the development of a new design of the rocker arm as a part cast from aluminium alloy.

BASIC ASSUMPTIONS

The design of the suspension system in mobile off-road vehicles implies the use of high-strength materials with a high safety factor. The examined components of the suspension system must be fully functional in every available area, and possible failure of one of the elements should guarantee continuation of the vehicle operation or possibly quick and easy replacement [8,9]. The possibility of structure and material conversion was examined on a transportation and rescue vehicle with an unladen weight not exceeding m = 3500 kg. The selected type of suspension system consists of six independently mounted wheels, including two drive wheels.

The lower rocker arm is a welded construction composed of 13 elements, and the whole structure weighs about 10.5 kg, while the upper rocker arm is welded from 9 elements and weighs approximately 8.5 kg. To make welded rocker arms, special tooling is needed to ensure the repeatability and dimensional consistency. The biggest problem is high labour input. The possibility of using casting as a replacement part is expected to considerably increase both the quality of workmanship and repeatability.

The design of a new construction of the rocker arm was based on the existing kinematic structure of the suspension (Figure 1), with particular emphasis put on the collision-free mating of the newly developed structure with the already existing suspension components, maintaining the so far existing mounting points.

The accepted load diagrams assume a uniform distribution of forces acting on individual wheels of the vehicle during transit through the rough terrain, including the loss of stability and extreme inequality of each wheel contact with the substrate [10].

For numerical analysis, an AlZnMgCu alloy was selected. The AlZnMgCu alloys are characterised by higher mechanical properties compared to the commonly used aluminium alloys with silicon. The tensile strength R_m after heat treatment varies within the range of 400-500 MPa. The disadvantage of these alloys is definitely lower resistance to fracture and poor ductility.

The main alloying elements are zinc and magnesium. The zinc-to-magnesium ratio in these alloys is greater than unity (Zn: Mg> 1). Iron and silicon are considered impurities. Other elements such as Zr, Mn, Cr have little effect on the structure strengthening, while Ti and Be serve as grain refiners. It is also assumed that Cu, depending on the content of Zn and Mg, is strengthening the structure, improving also the stress corrosion resistance.

RESEARCH

For the strength analysis, a 3D virtual model of a single-wheel suspension system, consisting of the upper and lower rocker arms, hydroactive actuator and steering knuckle, has been designed. Figure 1 shows model of the suspension system with the rocker arms so far made from the welded steel pipes and profiles.

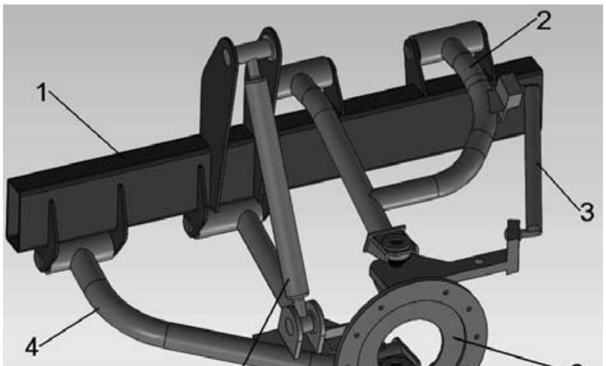


Fig. 1. Model of single-wheel suspension system in the examined vehicle: 1 – part of the vehicle frame, 2 – upper rocker arm; 3 – anti-roll bar, 4 – lower rocker arm; 5 – hydroactive actuator, 6 – steering knuckle

To identify the values of forces acting on individual nodes in the examined suspension system components, running on an experimental track with constant speed v = 15 km / h was simulated. During the simulation, maximum response values were determined for each node of the analysed fragment of the suspension system, assuming several criteria for the acting load.

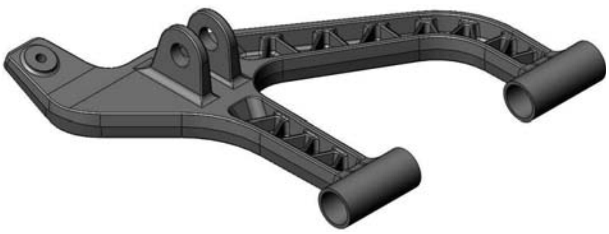
Additionally, a load diagram was examined for the suspension system of the vehicle during heavy braking on concrete in such a way as to obtain a delay of 8 m/s^2.

The design of cast rocker arms was developed with reference to the technology of their manufacture, assuming three different profiles of cross-sections, i.e. channel section, horizontal T-section, and vertical T-section. Models with more cast arm profiles developed in a CAD system are shown in Figure 2.

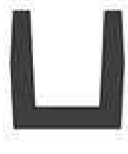
To analyse the cast structure loading mode, it is necessary to introduce data collected for the AlZnMgCu alloy. Laboratory investigations were carried out to determine parameters such as R_m, R_{p02}, and A_5. The fatigue behaviour of the AlZnMgCu alloy was also tested using modified low cycle fatigue test (MLCF) at different levels of the cyclic loading determined by finite element method (FEM) on an MTS 810 testing machine.

Models developed for simulation were imported to ANSYS. Based on the accepted kinematic suspension scheme and the preset pattern of loads acting on the suspension system during the drive, preliminary numerical calculations were conducted for the cast lower rocker arm.

Analysis covered all the conceptual designs shown in Figure 2 and the design of a welded rocker arm. The newly developed design was analysed as a part cast from the AlZnMgCu aluminium alloy, while welded rocker arm was analysed as a steel element.



a)



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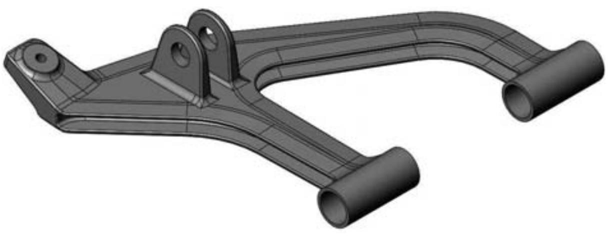

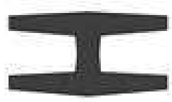

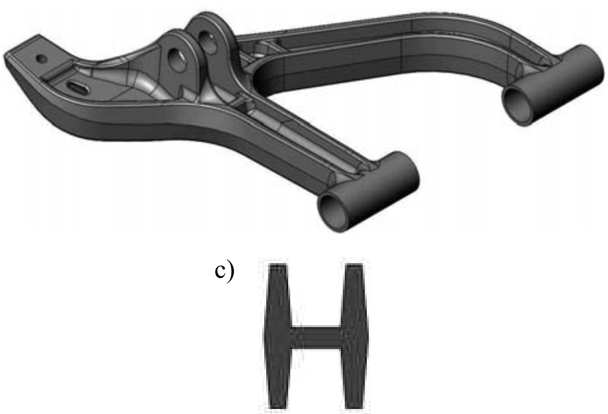

Fig. 2. 3D models of rocker arm with arm cross-sections ready for numerical analysis: a) – channel section (ribbed), b) – double-T horizontal section, c) – double-T vertical section

RESULTS

Based on CAD models, the weight of the newly developed structure was estimated and its percentage reduction relative to the actual structure of rocker arm made from prefabricated welded steel. For the designs shown in Figure 2, the obtained reduction of weight was:
– for cast channel section - 37.5%,
– for cast double-T horizontal section - 38.9%,
– for cast double-T vertical section - 29.4%.

Thus, the pre-designed structures have allowed triple weight reduction in cast component compared with the welded construction.

The results of the response of component forces in each node of the lower rocker arm set in a global coordinate system (GCS) are shown in Table 1.

Tab. 1. Responses obtained for selected loading modes at the lower rocker arm/ steering knuckle mounting point

Criterion	Component F_X,[N]	Component F_Y,[N]	Component F_Z,[N]
Loading mode I	-15 550	-7 547	14 559
Loading mode II	-12 915	-15 895	14 172
Loading mode III	-20 302	53 368	8 009
Loading mode IV	191	-10 847	9 604
Loading mode V	25 000	-5 000	-10 000

The heaviest load acting on the suspension system during simulation tests was obtained in the case of load operating on the outer surface of the wheel, i.e. in loading mode III. For the examined patterns of kinematic excitation, a maximum dynamic surplus coefficient was determined for the static vertical force operating on a wheel of approximately k_d = 2.5. Under the conditions of the dynamic loads applied, the adoption of this factor results in a higher value of the force acting on a suspension system than the force acting in the case of a quasi-static load. Then, the load acting on a single rocker arm will be twice as high as the static uniform load acting on all wheels of the vehicle [11, 12].

The algorithm for a modified low cycle fatigue test MLCF allows the estimation of mechanical properties of the material in a single test based on the results of analysis of the fatigue curve characterised by a gradually increasing value of the amplitude of force until failure of the specimen [13]. The accommodation limit R_{AK} is defined as a stress value below which the strain increment is less than or equal to 0.1%. Table 2 compares the results obtained during MLCF tests performed on rod-shaped specimens with a diameter of 6.5 mm.

Tab. 2. The mechanical properties obtained in laboratory studies for an AlZnMgCu alloy (ε_{max} – the maximum allowable strain for 20x10^6 cycles).

Tensile strength R_m [MPa]	Elongation A_5 %	Yield strength R_{02} [MPa]	Elastic modulus E [MPa]	Fatigue strength Z [MPa]	Accommodation limit R_{AK} [MPa]	ε_{max}
431	1.18	417	68669	159	151	0,3

Table 3 compares the data obtained for an AlZnMgCu alloy with the strength parameters of the material currently used.

Tab. 3. Basic mechanical properties of the rocker arm material adopted for the numerical analysis of a loading process

Material	Elastic modulus [MPa]	Tensile strength [MPa]	Yield strength [MPa]	Density [kg/m^3]
AlZnMgCu alloy	72000	430	417	2795
Structural steel	205000	945	890	7850

The results of calculations of the stress distribution for loading mode III are shown in Figure 3. The adopted load limit has been reduced to 400 MPa to better illustrate the distribution of the maximum stress fields in a welded steel rocker arm and in the preliminary cast structure design.

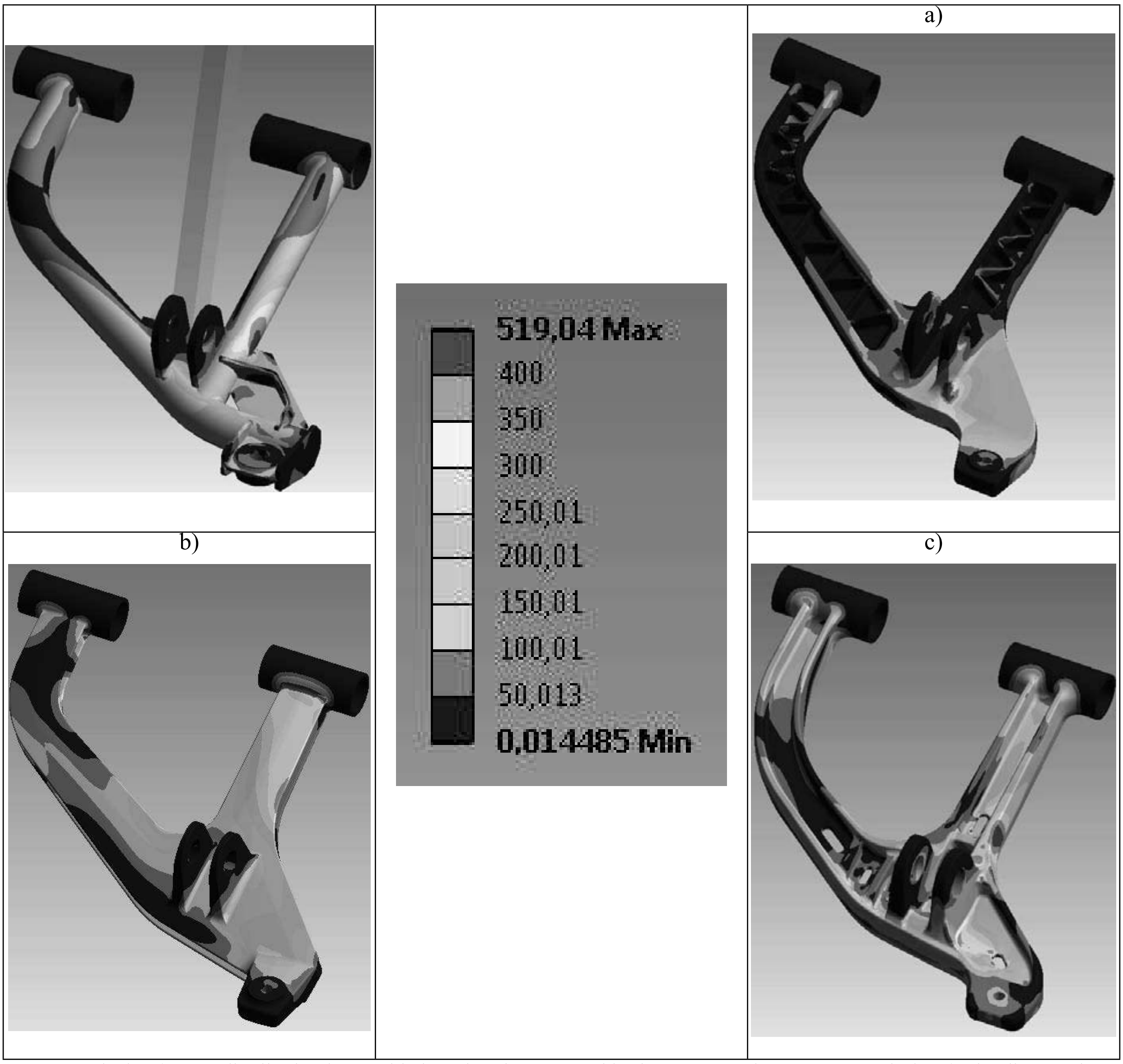

Fig. 3. Analysis of stress distribution in a welded steel rocker arm and in the conceptual cast structure design for loading mode III

Calculations have shown that, given the casting process potentials and the effect of the proposed cross-section shape on the distribution of the maximum stress field values, an optimal shape has the design of a double-T vertical profile (model c in Fig. 2). The design optimisation in terms of the reduced weight of an element while maintaining at the same level the expected maximum stress values or, if possible, reducing them in a substantial way, helped to decrease the weight of the cast aluminium rocker arm to 7.9 kg, which means a 25% reduction in weight obtained on a single element [14].

The maximum reduced stress values (according to von Mises), occurring in the sensitive areas of the analysed structure of the lower rocker arm casting, determined for each loading mode, are compared in Table 4, while distributions of the stress field values are shown for selected loading modes in Figure 4.

Tab. 4. Maximum stress values for different loading modes

	Loading mode I	Loading mode II	Loading mode III	Loading mode IV	Loading mode V
Maximum stress [MPa]	189	198	301	131	221

The maximum displayed values of the stress fields have been reduced to 150 MPa to enhance the visibility of the most overloaded areas.

The next step in an optimisation of the geometry of the converted lower rocker arm design allowed reducing the maximum values of stresses occurring in the casting during loading at a given dynamic surplus coefficient. The maximum values of stresses occurring in the original welded design of the lower rocker arm, estimated from the results of numerical analysis (Figure 2), reached the values

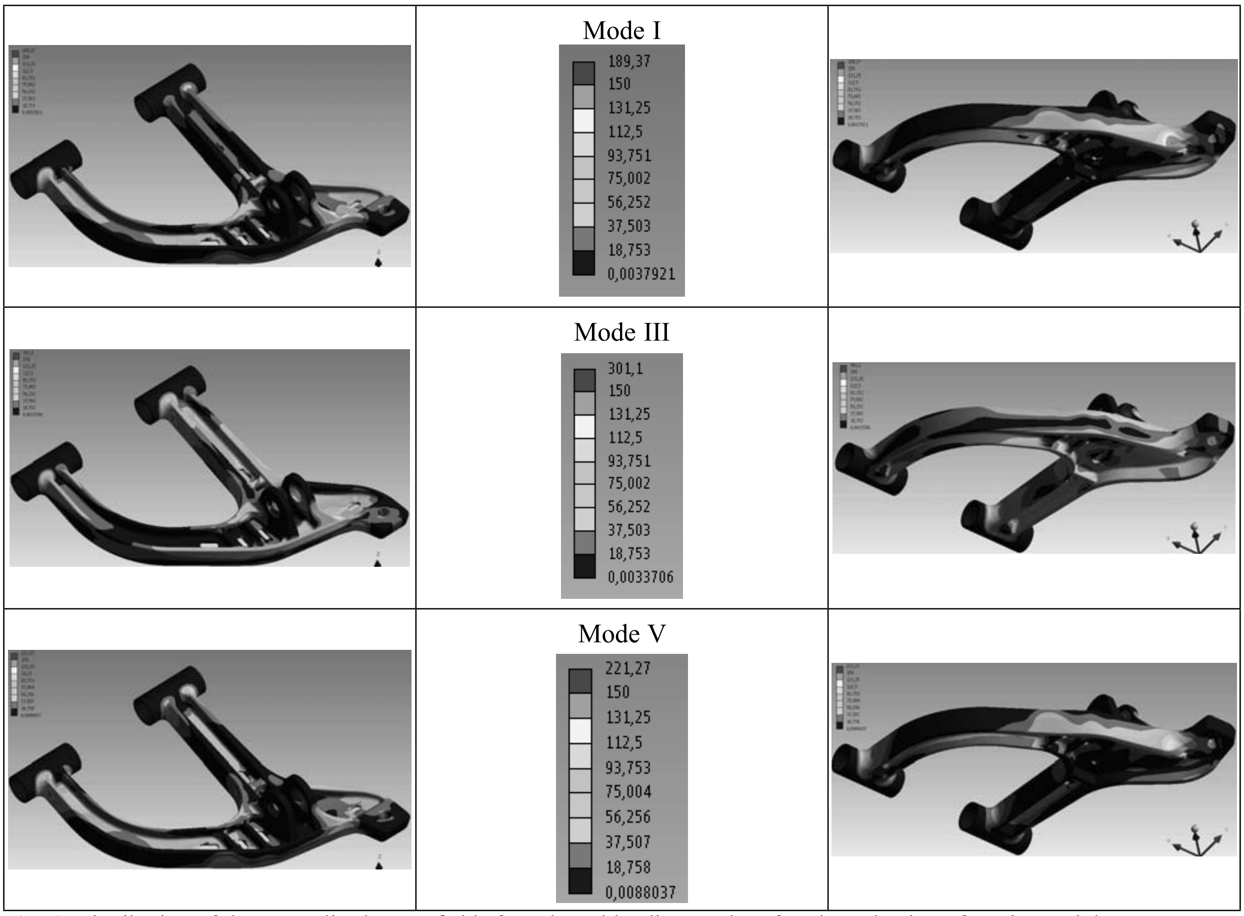

Fig. 4. Distribution of the generalised stress fields for selected loading modes after the reduction of casting weight

of about 520 MPa for loading mode III. In the case of the rocker arm cast from an AlZnMgCu alloy, the maximum stress values for the same loading mode were 301 MPa. As the analysis shows, the maximum stress in the newly developed structure constitutes about 72% of the yield strength, whereas in the case of the welded construction, this value constituted about 60% of the yield strength.

An analysis of the distribution of maximum stresses shows that, at the adopted loading modes, stresses are concentrated in the predetermined areas of controlled damage, i.e. precisely there where they were expected to occur, without affecting the rocker arm and actuator mounting points.

The newly designed cast rocker arms were introduced to the suspension model and tested for a collision-free cooperation of the whole system. Figure 5 shows a CAD model of the suspension system with the newly designed rocker arms.

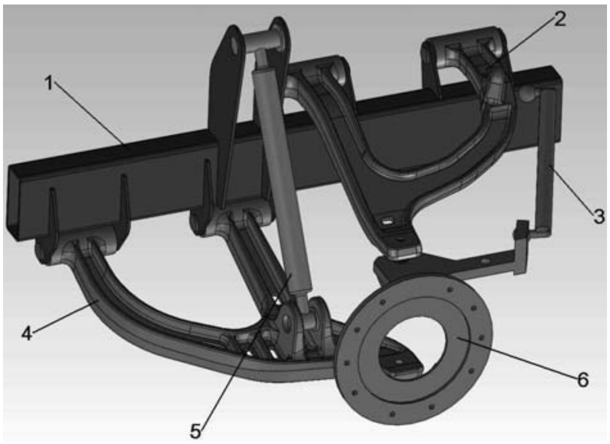

Fig. 5. Model of single-wheel suspension system in the examined vehicle with the newly designed cast rocker arms

CONCLUSIONS

1. Based on numerical calculations, the design of a rocker arm was developed, whose cross-section is a double-T vertical profile.
2. The maximum value of reduced stresses (von Mises) for the most unfavourable loading mode is 300 MPa, which represents 72% of the yield strength of an AlZnMgCu alloy.
3. The maximum stress location is in the areas of the preset controlled damage, and thus in the areas where damage can occur without affecting the rocker arm and actuator mounting points.
4. Optimising the design and the use of aluminium alloys for cast parts enabled reducing the weight to 7.9 kg, i.e. by 25%, compared with the welded structure.
5. The conducted analysis shows that the developed cast rocker arm design meets the performance requirements adopted for special-purpose vehicles.

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WYKORZYSTANIE ZINTEGROWANEGO SYSTEMU PROJEKTOWANIA DO OPRACOWANIA KONSTRUKCJI WAHACZA DLA POJAZDU SPECJALNEGO PRZEZNACZENIA

Streszczenie. Zamiana elementów spawanych na jednolite konstrukcje odlewane, przy zastosowaniu nowoczesnych tworzyw odlewniczych przyczynia się do poprawy właściwości użytkowych nowoopracowanej konstrukcji. Wykorzystanie nowoczesnych technik komputerowych pozwala zintegrować działania konstruktorów, technologów i wykonawców poszczególnych elementów w ujednoliconym procesie ICME. W opracowanej konstrukcji wahacza zastosowano wysokowytrzymały stop AlZnMgCu, w celu obniżenia masy poszczególnych elementów zawieszenia i zwiększenia dokładności wymiarowej uzyskanych konstrukcji wahacza. Przeprowadzone badania obejmowały zakres opracowania nowej konstrukcji na podstawie istniejącego elementu stalowego wraz z szeregiem analiz wytrzymałościowych i weryfikacji komputerowej opracowanej technologii odlewania dla wahacza dolnego stosowanego w pojazdach specjalnego przeznaczenia.

Słowa kluczowe: symulacje numeryczne, wysokowytrzymałe odlewy aluminiowe, konwersja materiałowo-konstrukcyjna, zawieszenie pojazdów mobilnych.