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Shaping the Strength of Cast Rocker Arm for Special Purpose Vehicle

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Abstract

The article discusses the weldment to casting conversion process of rocker arm designed for operation in a special purpose vehicle to obtain a consistency of objective functions, which assume the reduced weight of component, the reduced maximum effort of material under the impact of service loads achieved through topology modification for optimum strength distribution in the sensitive areas, and the development of rocker arm manufacturing technology. As a result of conducted studies, the unit weight of the item was reduced by 25%, and the stress limit values were reduced to a level guaranteeing safe application.

Keywords: Computer-aided foundry production, Design optimization, High-strength aluminium alloy

1. Introduction

Current methods used in structural design involve multidisciplinary approach to cooperation between engineers, designers and technologists, and often also end product users, at the stage of material selection, shape development, and determination of functional and performance properties – all this combined with manufacturing cost reduction. However, numerous solutions existing on the market are still based on the designs developed many years ago, when the ratio of ultimate strength to the finished product weight was of no particular importance. The process of adapting these structures to the realities of the market must also take into account the optimization of production costs while maintaining safe operation.

The aim of the conversion in both material and design is to reduce the weight of the manufactured item or improve its performance, while maintaining the expected or desired mechanical properties and operating parameters. The process of changing the size, shape or free surface of the element, taking into account changes in material or technology, is an extension of the shape optimization or topology optimization process, assuming the development of a structure with adequate stiffness and strength when exposed to the effect of external loads. [1-3] The use of modern computing systems can significantly reduce the time spent in searching for an optimum of the assumed objective functions, taking into account, among others, a relationship between the finite element stiffness and its placement in a discretized workspace. Analysis of optimization, conducted on the basis of multiple iterations, mainly consists in the removal of finite elements from the areas of the analyzed continuum for which the stiffness does not exceed the limit value, resulting in a topology model of the structure with optimum contour for a given objective function (Fig. 1).

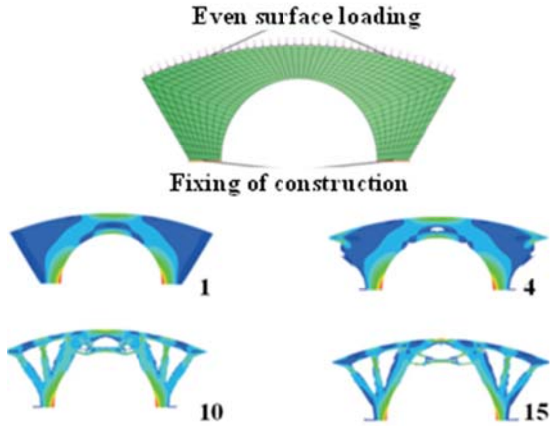


Fig. 1. Optimization of supported arched design evenly loaded from the top [2]

An extension of the conducted analysis can include changes in the material used for a given structure, while maintaining the existing interactions and transfer of assumed limit loads [4].

The development of a new design demands from the engineer identification of loads, boundary conditions, fixing points, and interaction between the assembly components under real operating conditions. Identification of complex loads operating in the analyzed structure aims at the determination of static forces and moments, using next the components of these forces and nodal loads at a later stage of the numerical stress analysis. For several years, at the Foundry Research Institute, research and implementation projects have been conducted to deal with the problem of conversion, both in material and design, of items forged or welded into castings [5-8].

2. Main assumptions of the conversion in material and design

The aim of this work was shaping the strength of rocker arms welded from steel profiles to prepare them for conversion into items cast from high-strength aluminium alloy. Another aim of the work was to obtain the maximum weight reduction in components of the suspension system and examine the system capabilities of transferring the preset service loads. The examined design of the suspension system is used in special purpose vehicles based on the mobile LEWIATAN platform with six independently mounted wheels, where the kinematic system of a single wheel includes upper and lower rocker arms and a hydroactive actuator with hydropneumatic spring elements. Lower rocker arm is welded from 13 shaped elements with a total weight of about 9.7 kg; the upper rocker arm is welded from 9 components of the total weight of 8.5 kg.

The newly developed design takes into consideration the structural and operational assumptions adopted for mobile unmanned objects resistant to the IED (Improvised Explosive Device) type threats and ensures [9]:

- maximum resistance to dynamic forces arising from the use of the vehicle in difficult terrain, provided by the application of advanced, high-strength materials and a high safety factor;
- destruction of the element by IED in a specially designed construction node, which will enable rapid and modular replacement of components with no harm to the vehicle mobility.

The new design of the cast rocker arm provided with a zone of "controlled destruction" was based on the kinematic suspension system used so far (Fig. 2), preserving the existing fixing points and collision-free cooperation between components.

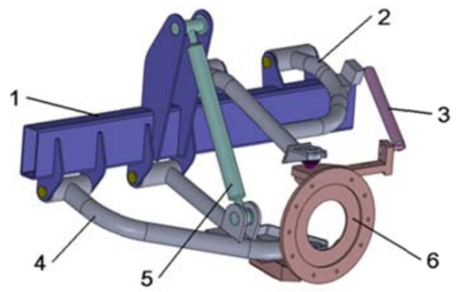


Fig. 2. Virtual model of the suspension system structure used so far: 1 – vehicle frame, 2 – upper rocker arm, 3 – anti-roll bar, 4 – lower rocker arm, 5 – hydroactive cylinder, 6 – steering knuckle

The developed kinematic model of the suspension system was used in the identification of loads that occur during operation of the examined mobile object. Maximum excitation forces acting on the vehicle wheel were determined, assuming different patterns of the operating loads. Based on the results obtained, reactions in individual kinematic nodes of the suspension system were estimated. [8] The optimization analysis of the rocker arm design was based on the adopted criterion of maximum resultant force acting on the system, allowing for an almost 2.5 times heavier load in respect of the criterion of stable vehicle driving on a level ground. Table 1 shows reactions, which occur in the kinematic nodes of individual rocker arms operating in the system, based on a numerical analysis allowing for the adopted load criterion.

Table 1.
Values [illegible] reactions in the structural nodes of rocker arms during loading of the wheel with maximum resultant force

Reaction /component	Upper rocker arm		Lower rocker arm
	Steering knuckle mounting	Bar mounting	Steering knuckle mounting
R [N]	13 164	9 878	27 643
R_X [N]	9 136	-2 769	-15 981
R_Y [N]	8 493	-8 118	-15 532
R_Z [N]	-4 207	4 900	16 357

Based on the results of numerical analysis of the process of loading the welded rocker arm structure with loads of a preset value, the allowable stress limits to be met by the new structure, and thus by the casting alloy used for this structure, were specified. The minimum values [illegible] for the newly developed structure are as follows: Rm=min. 415 MPa, Re=min. 340 MPa and an elongation of minimum 2%. The adopted manufacturing technology and the specific conditions of operation also demand from the rocker arm material a good castability, corrosion resistance and machinability. The required parameters must be observed also in the finished cast product.

Recent tendency adopted in the design of structural components of a suspension system is to significantly reduce the unsprung weight. In special purpose vehicles, for which air transport is often necessary, a reduction of the total weight is also of primary importance. Using high-strength aluminium alloys as a casting material allows full utilization of their potential, which is a much lower specific gravity, and through appropriate shaping of the casting profile, obtaining and maintaining the required strength parameters, similar to materials with much higher specific gravity [10]. Properly designed aluminium structure should provide even double weight reduction compared to the initial design made of ferrous alloys.

Analysis of high-strength aluminium alloys focussed on the 7xxx series alloys, which are not typical casting alloys, but through modifications introduced to their chemical composition, mainly as regards zinc and magnesium content, can be effectively used for the responsible structures of suspension system components.

For studies, an AlZnMgCu alloy containing 5.5% Zn and 1.6% Cu was selected. For this casting alloy in the heat treated condition, the expected tensile strength of 420-480 MPa was obtained but not the required ductility, which was at a level of $A_5 \leq 1.5\%$. So, further development studies focussed on the problem of raising the ductility of the tested alloy through changes in the chemical composition and heat treatment process, considering the possibility of increasing its resistance to fatigue failure under the effect of variable dynamic loads at the expense of reduced strength of the resulting material [11-14].

3. Shaping the structure of suspension system components

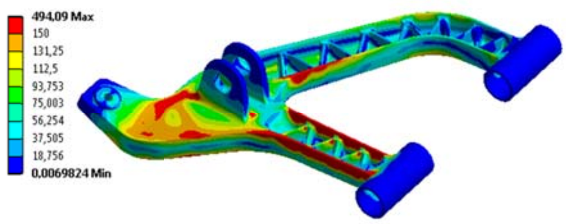
The specific conditions under which the special purpose vehicle operates anticipate the possibility of using the existing chassis not only as a platform for building a civil vehicle (unmanned vehicle for transport, firefighting or chemical assistance), but also as a platform for a vehicle used in peacekeeping missions for transport or reconnaissance and combat. The main assumptions on the possible transfer of service loads allow taking advantage of the design of rocker arms whose weight is comparable to or even higher than the original design. Because of the military-rescue function of the mobile platform, an essential reduction in the weight of its components is necessary to enhance the protection of transported passengers or cargo. To obtain higher resistance to the effect of explosive charges, the majority of special purpose vehicles have a V-shaped design of the chassis, allowing for a better dispersion of the shock wave resulting from explosion, and use additional guards to protect persons transported. Unfortunately, the suspension elements can not be protected, because at any time the vehicle is moving they change their position. The development of structural components of a suspension system assumes the choice of profiles and surface area such that will best dissipate the shock waves acting on the lower zone of the vehicle chassis and take over a considerable part of the energy of explosion, even at the expense of destruction of the examined suspension component.

The originally developed design assumed a U-shaped cross-section and a horizontal I-shaped cross-section of the rocker arms, to obtain, in addition to load transfer during driving, also maximum dispersion of the pressure wave caused by an IED explosion. The lower rocker arm designs developed for the two adopted cross-sections are shown in Figure 3.

Fig. 3. The proposed two designs of the rocker arm cross-section: a) U-shaped profile, b) I-shaped profile

The proposed design enabled the rocker arm weight to be reduced by 30% compared to the weight of the original part. The results of studies of material effort in the newly developed rocker arm design, loaded by forces complying with the maximum resultant force criterion, are presented in Figure 4 for both model versions of the design.

a)



b)

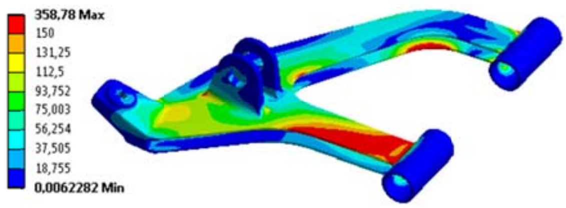


Fig. 4. Reduced stress distribution [MPa] in the lower rocker arm of U-shaped cross-section (a) and I-shaped cross-section (b)

The stress values occurring in the examined structures, amounting to 495 MPa for the U-shaped profile and to 395 MPa for the I-shaped profile, significantly exceeded the allowable stress limits, but successive approximations of the topology of both designs of the lower rocker arm during numerical analyses carried out for the assumed loading criteria failed to give a design that would transfer the assumed limit loads.

Based on the results of previous numerical analyses, the design of a rocker arm has been developed, where the elements have the cross-section of a vertical I-beam with shape varying along the arms length. The proposed cross profile of the arms was adopted as an optimal one in terms of its stiffness and the lowest possible operating stress values, where additionally the zones of "controlled destruction" should absorb a large part of the energy of the pressure of explosion, eliminating the threat of damage to the hull of the vehicle chassis. A model of the developed structure is shown in Figure 5.

Fig. 5. Model configuration of the lower rocker arm with an I-shaped cross-section.

The maximum reduced stresses obtained on loading of the rocker arm according to the criterion of maximum exciting forces do not exceed 200 MPa, and the field of stress concentration is located in the zone of "controlled destruction". Figure 6 shows maximum values of operational stresses for the assumed load criterion and the size of generalized displacements.

a)

b)

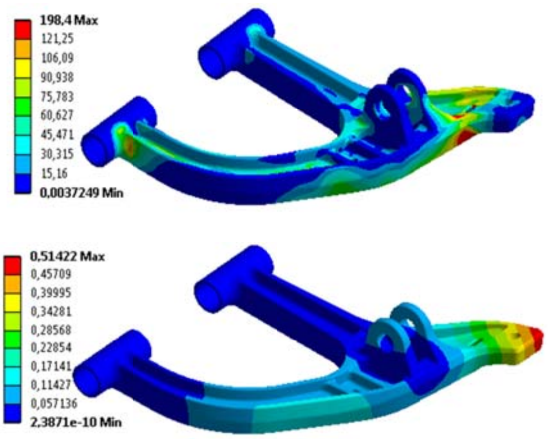


Fig. 6. The cast rocker arm showing the distribution of reduced stresses [MPa] (a) and generalized displacements [mm] (b)

4. Conclusions

The lower rocker arm design developed for an aluminium alloy casting meets the basic operational requirements. It does not transfer loads acting on the fixed parts of the vehicle chassis and in the case of destruction its replacement is done by a simple procedure. The resulting profile of the rocker arm is a compromise between the state of the allowable stress limit and the possibility of making this element as a prototype casting in small lot production. Successive approximations in the strength shaping process of the rocker arm topology helped reduce its weight from 9.7 kg to 7.25 kg. The weight reduction obtained on all rocker arms operating in the suspension system of a vehicle gave the total value of almost 30 kg.

Studies on the possible use of AlZnMgCu alloys for the cast components of a suspension system allowed developing a methodology for the heat treatment of finished products to obtain materials with the desired strength properties.

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