DEVELOPMENT OF METHODOLOGY FOR MULTIAXIAL DYNAMIC TESTING OF MATERIALS FOR AUTOMOTIVE CONSTRUCTION GROUPS

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Abstract

The current automotive industry requires weight savings in the components used in the production of vehicles. At the same time, however, the demand for safety, high strength and fatigue life is increasing. This study aims to create a comprehensive methodology that will help designers and material engineers choose the appropriate technical solution and material for a highly stressed axle element. Specifically, the possibility of replacing the front axle weight produced from ductile iron with a high-strength aluminium alloy EN AW-7075 in T6 condition is addressed. As part of the solution concept, a 3D model was created and, using the finite element method (FEM), a simulation of the response of the mass to the load corresponding to traffic on the road was carried out. Furthermore, the technological procedure for testing automotive components using a multi-axis dynamic testing facility was established, where the DIC (Digital Image Correlation) method was used to evaluate load states and deformations. The basic limit states of vehicle operation, braking and cornering were tested. The work also deals with material factors that influence the choice of a suitable alloy, and verification of the degree of safety of the structural and material solution. The measurement results from both methods were compared with the contractual yield strength and fatigue strength. The results of FEM simulations and measurements using DIC positively verified the possibility of changing the material of the block, from ductile cast iron to EN AW-7075 strength aluminium alloy in T6 condition. The described methodology can therefore be used in the design, construction and implementation of car prototype chassis.

Keywords: Front axle beam, FEM, DIC, AW-7075 T6

1. INTRODUCTION

Currently, the development of the automotive industry is experiencing an upswing, and scientific fields are responding to its requirements to develop, innovate or replace commercially used technical car materials with newer ones with a lower specific weight, a comparable yield strength and a declared fatigue life, and then applying these materials to serial production. There is a need to minimize the ecological footprint of production and proceed with the use of renewable resources. Economic indicators are gaining importance and the profitability of the technical materials used is reflected in the price of the product. Among the very important parameters it is also the guarantee of the safety of car operation about the strength and fatigue life of structural groups in which these materials will be implemented.

The issue of the use of multi-axis dynamic testing of materials offers the possibility of a solution for automotive construction groups in prototyping or optimization assignments to reduce vehicle weight and fuel consumption, increase range with lower exhaust gas emissions, passive and active safety of the crew, degree of plastic deformation of the car during crashes (crash tests), but also on the economy of operation and the price of the vehicle [1].

The work deals with creating a comprehensive methodology designed for real load conditions to verify the design and functionality of the structural group - the front axle beam. FEM calculations can be used to simulate loads and deformations of the 3D model of the tested front axle beam in the *x*, *y* and *z* axes [2,3]. The principle of FEM is the actual simplification of the entire assignment of the problem. Large areas are divided into several smaller, simpler areas. These simpler parts are designated as finite elements [4]. A multi-axis dynamic testing facility capable of creating these loads was chosen to carry out real load tests. Deformations of the front axle beam were optically measured using the digital image correlation method (DIC) during cornering and maximum braking conditions [5,6,7].

2. DESCRIPTION OF THE MATERIAL

The high-strength aluminium alloy EN AW-7075 in T6 condition was chosen as an innovative material. Not only the aluminium alloy EN AW-7075 T6 was subjected to the material analysis, but also a front axle beam commercially produced from ductile iron for comparison. Specifically, samples were taken and measurements were made from the original front axle beam of the Skoda Octavia car. The chemical composition of the aluminium alloy was verified using a SpectroMax Spark Optical Emission Spectrometer (S-OES - see **Table 1**). The chemical composition of the original part was determined using the Glow Discharge Optical Emission Spectroscopy (GDOES) method on the Spectrum device (**Table 2**).

Table 1 Aluminium alloy chemical composition verified by S-OES (wt%)

Al	Si	Fe	Cu	Mn	Mg	Cr	Zn
89.90	0.03	0.10	1.63	0.03	2.15	0.20	5.87
Ti	**Ni**	**Ag**	**B**	**Be**	**Bi**	**Ca**	**Cd**
0.036	<0.001	0.0021	0.0012	0.0005	<0.001	0.0006	<0.0001
Co	**Li**	**Na**	**P**	**Pb**	**Sn**	**Sr**	**V**
<0.0001	<0.0002	<0.0001	0.002	0.0039	0.0026	<0.0001	0.0039

Table 2 Chemical composition of the original part determined by GDOES (wt%)

C	Mn	Si	P	S	Cr	Ni	Mo	Cu
2.91	0.06	2.45	0.018	0.003	0.02	0.04	0.003	0.078
Ti	**Co**	**B**	**Pb**	**V**	**W**	**Zr**	**Al**	**Nb**
0.008	0.002	0.001	<0.001	0.001	<0.001	0.002	0.010	0.002

The hardness of the evaluated materials HBW 2.5/62.5 was measured using a DuraScan G5 hardness tester. The measurement results are summarized in **Table 3.** The prototype front axle beam made of EN AW-7075 T6 alloy showed a higher hardness of 183 ± 2 HBW 2.5/62.5. For the original front axle beam, a higher dispersion of the measured hardness values was found due to the different microstructure in different places of the casting.

Table 3 The hardness of the evaluated materials is HBW 2.5/62.5

Front axle beam/material	HBW 2.5/62.5
Front axle beam /EN AW-7075.T6	183 ± 2
Front axle beam original/ductile iron	160 ± 22

From the material of the prototype front axle beam from alloys EN AW-7075 T6 four tensile test specimens were made with a diameter d_0 = 8 mm and tested length L_c = 55 mm in the transverse direction relative to the forming direction. The original measured length was L_0 = 40 mm. These test specimens were loaded at speed v = 2 mm/min. The yield strength $R_{p0.2}$ = 478 ± 7 MPa, ultimate tensile strength R_m = 571 ± 10 MPa and ductility A_5 = 6.1 ± 0.6 % were determined by a tensile test. For aluminium alloy EN AW-7075 in condition, T6 (solution annealing + cooling down+ artificial aging) according to [8] must be met the aluminium alloy for plates with a thickness of 12.5 to 25 mm minimum requirement for the contractual yield strength $R_{p0.2}$ = 470 MPa and for tensile strength R_m = 540 MPa, which was fulfilled. The value of the modulus of elasticity in tension E was not determined from the tensile test, but according to [8] must be at least 71.7 GPa.

3. MEASUREMENT METHODOLOGY

The production of the front axle beam from EN AW-7075 T6 aluminium alloy material was carried out in the laboratories and workshops of the Department of Materials and Technologies for Automobiles, FMST, VŠB-TU of Ostrava. According to the drawing documentation, CNC milling was used. During production, we considered the anisotropy of the rolled aluminium alloy product and solved the orientation of the rolled structure concerning the load directions so that it was in the direction of the main loads, thereby supporting the life and resistance of the front axle beam. **Figure 1** shows a model for experimental measurement purposes. Since the weight is a safety-relevant part of the vehicle's front axle, it is necessary to have a processed analysis of the forces acting in real traffic. This information is used to determine material criteria. Forces and loads are variable and must be based on driving limit states. To determine it, we use the equations of motion [9]. For these purposes, the moments of forces acting during cornering and braking were chosen.

The size of the loading forces is based on the calculation relationship when the weight of the vehicle is added m_1 and the weight of the driver and passengers m_2. The weight of the SCX3 vehicle was calculated during the experiment m_1 = 1520 kg and the weight of the crew and cargo m_2 = 300 kg, i.e. the total weight considered was 1820 kg. For measurement purposes, the force acting on the tire was calculated at 4000 N.

Using the FEM method, the load during the braking and cornering process was calculated. The construction of the front axle beam must be robust enough to be able to transfer these forces and loads. For the FEM calculation, eight load states were determined according to **Table 4**. The places with the largest deformations of the so-called critical area occurring on the tested structural component were specified (**Figure 2**). These areas were subsequently experimentally verified in a multiaxial dynamic load condition.

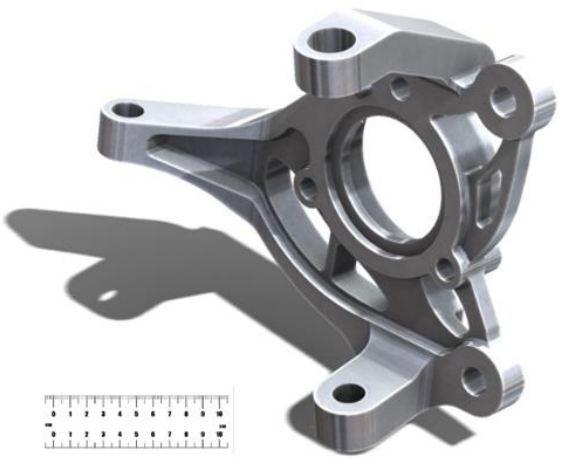

Figure 1 Front axle beam designed for experimental measurements from EN AW-7075

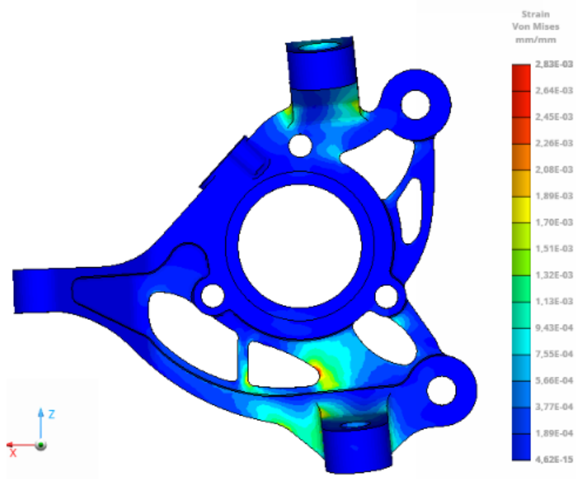

Figure 2 Simulating the load on the block using FEM in the state at x = 4 kN, y = 0 kN and z = 4 kN

Before the experimental measurement, the front axle beam intended for the prototype vehicle was placed on a multi-axis dynamic test bench (**Figure 3**) and the position of the brake disc was fixed using a screw connection so that it does not slip (move) during the simulation of the braking condition. Before starting the measurement, the starting position was determined, when only the vertical load was applied, which expresses the weight of the vehicle in the z-axis. Experimental loading of the front axle beam was performed by a hydraulic cylinder that developed forces *F* according to **Table 4.** Forces were measured using built-in strain gauges. The entire front axle beam was optically scanned by two cameras during loading. The optics of the DIC method will focus on coloured dots sprayed on a contrasting background and their relative displacement will be captured using the recording. The software then compares and evaluates the magnitude and direction of mutual displacement relative to their position at the beginning of the measurement and determines the deformations from them. Subsequently, it is possible to focus in detail on the area with the greatest degree of deformation, which was the subject of interest. In this area, it is possible to analyse in detail the size of the displacement, and the size of the load (**Figure 4**).

Table 4 Forces at driving limit states (N)

Load states		Axial load (N)		
		x	**y**	**z**
1	Resting-state	0	0	4000
2	Brake, moderate	2000	0	4000
3	Brake, full	4000	0	4000
4	Brake after passing through a slight curve	4000	2000	4000
5	Brake when passing through a full curve	4000	4000	4000
6	Pass through a slight curve	0	2000	4000
7	Passing through a full curve	0	4000	4000
8	Resting-state	0	0	4000

Figure 3 Fixation of the aluminium front axle beam on the dynamic test bench

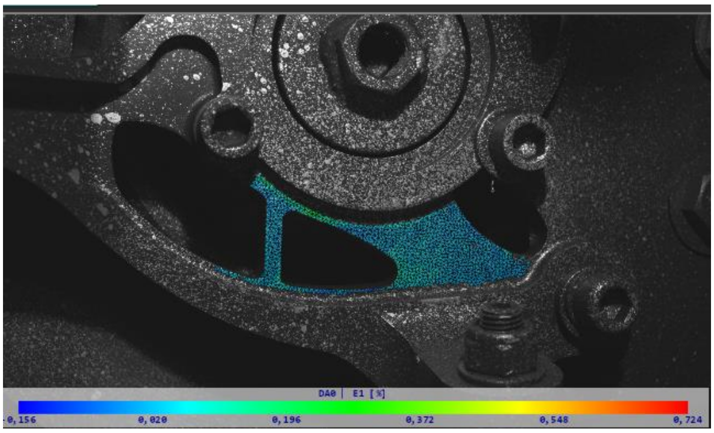

Figure 4 Record of DIC measurements at x = 4 kN, y = 0 kN and z = 4 kN

4. RESULTS AND DISCUSSION

In **Table 5** we recorded the magnitudes of the maximum deformations $\boldsymbol{\varepsilon}$ measured using FEM in individual load states. **Figure 5** shows the load status No. 3 (x = 4 kN, y = 0 kN a z = 4 kN), in which the maximum rate of deformation was found $\boldsymbol{\varepsilon} = 2.83{\cdot}10^{-3}$ mm/mm, ie. 0.283 %. This is the state of braking until the tire slips. DIC measurements shown in **Figure 4** the distribution of deformations in the entire volume of the front axle beam. By experimental measurement using the DIC method, condition No. 3 was also evaluated as the condition with the greatest degree of relative deformation. In **Table 5** and **Figure 6** we can find the maximum measured strain value detected by the DIC method ε = 0.234 %. The differences in the outputs from FEM and DIC ranged around 20 % (out of state No. 6). These differences are probably related to the lower stiffness of the distribution rods for load transfer in the *x*, *y* and *z* axes. According to Hook's law, the maximum stress value of 203 MPa was calculated for the modulus of elasticity in tension E = 71.7 GPa at the points of maximum deformation.

Table 5 Values of maximum deformations $\boldsymbol{\varepsilon}$ in % measured using FEM and DIC

Load condition	1	2	3	4	5	6	7	8
FEM	0.134	0.200	0.283	0.270	0.280	0.143	0.275	0.204
DIC	0.114	0.170	0.234	0.219	0.220	0.049	0.220	0.171
Standard deviation	14.9	15.0	17.3	18.9	21.4	65.7	20.0	16.2

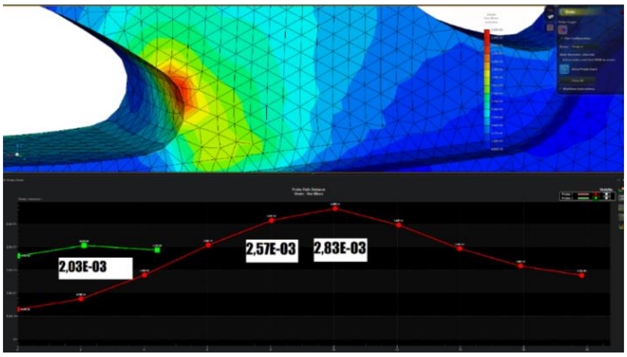

Figure 5 FEM location of largest deformation for load No. 3, $\boldsymbol{\varepsilon}$ = $2.83 \cdot 10^{-3}$ mm/mm

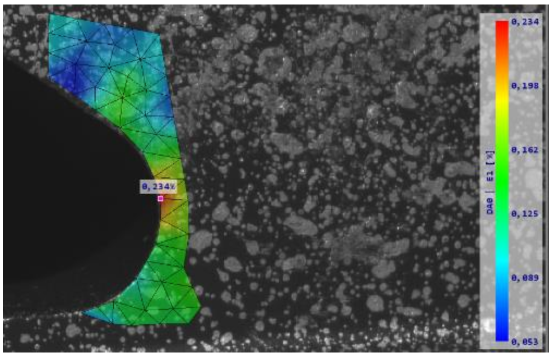

Figure 6 The place with the greatest degree of deformation by the DIC, $\boldsymbol{\varepsilon}$ = 0.234 %. No. 3

5. CONCLUSIONS

As part of the work, the results of the FEM simulation and measurements using DIC were compared. The work aimed to determine the place on the front axle beam that shows the greatest deformation. Aluminium alloy EN AW-7075 in the T6 condition exhibits a contractual yield strength $R_{p0.2}$ = 478 MPa.

The experiment proved that the maximum load was reached within the driving conditions σ_{max}= 202 MPa, which corresponds to 42% $R_{p0.2}$. Multi-axis dynamic bench testing and FEM analyses have shown that the designed EN AW-7075 aluminium alloy in the T6 condition is satisfactory for use on the prototype vehicle. The created methodology can be used in the design of new prototype components, where the goal is to reduce the weight of the used components, fuel consumption, emissions and at the same time increase the range of the vehicle.

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