

# The Composite Control Arm – Analysis of the Applicability in Conventional Suspension

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**Abstract** The paper presents the theoretical discussion on the possibility of replacing the actual design of the steel control arm of the car produced today by the structure made of polymer composite. Today exist the solutions of the whole suspension using composite materials and it is justified by the synergy effects possible to obtain. These solutions are characterized by smaller unsprung masses and higher damping.

**Keywords:** control arm, polymer composite, motor vehicle

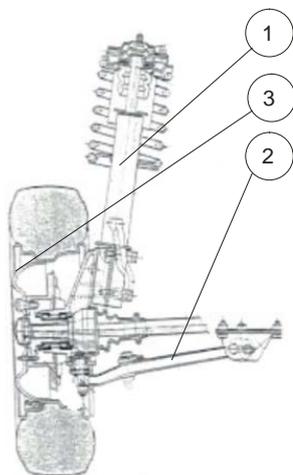
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## 1. Introduction

In this paper a theoretical analysis of the possibility of replacing the steel control arm of the MacPherson column suspension by the composite control arm has been carried out. The front suspension of the segment B passenger car was analyzed with the following assumptions:

- composite arm is fully interchangeable with steel control arm,
- strength of the composite control arm is comparable to the strength of the steel arm.

Figure 1 shows a schematic of the typical construction of the front suspension containing MacPherson column. The main elements of the suspension of this type are the springing column (Figure 1, item1) and the lower control arm (Figure 1, item2).



**Figure 1.** MacPherson Suspension: 1-column, 2-lower control arm, 3-wheel disk

The steel control arm of the analyzed suspension is presented on Figure 2 (below). The control arm is made of two drawpieces welded on the edges. The spherical pin (Item 3) connects the control arm with a steering knuckle and rubber-metal bushings (Item 2) attach it to the vehicle body.



**Figure 2.** Steel control arm: 1-drawpiece, 2- rubber-metal bushing, 3-spherical pin

In the suspension with a springing column the lateral control arm carries only the horizontal lateral and longitudinal forces. They are limited by the friction between the tire and the road (1).

$$F_t = \mu \cdot Q_k \quad (1)$$

where:

$F_t$  - lateral horizontal load; for  $i = p$ , lateral load;  $i = w$ , longitudinal load,  $\mu$  - coefficient of friction between the tire and the road,  $Q_k$  - maximum vertical load on wheels

The maximum longitudinal forces acting on the driven front wheels are the maximum attainable braking forces. The maximum lateral forces acting on the wheels are produced while driving the vehicle on the road arc on the limit of slip.

The loads acting on the wheel and the lateral lower control arm is schematically presented on Figure 3. The

control arm load ( $R_B$ ) can be determined using the well known equilibrium conditions.

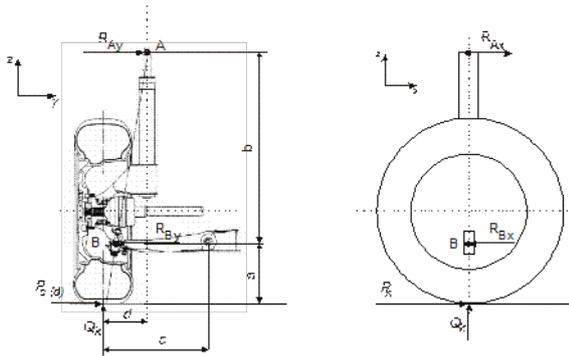


Figure 3. The load of the lateral lower control arm of the column suspension

In the Z-Y plane the loads can be determined from the relationships:

$$R_{By} = \frac{Q_k (a+b)(\mu + tg \delta)}{b} \quad (2)$$

Whereas in the Z-X plane :

$$R_{Bx} = \frac{Q_k \mu (a+b)}{b} \quad (3)$$

And thus:

$$R_B = \sqrt{R_{Bx}^2 + R_{By}^2} = \frac{Q_k}{b} \sqrt{(a+b)^2 (2\mu^2 + 2\mu tg \delta + tg^2 \delta)} \quad (4)$$

where:

$R_B$  - load of a control arm,  $P_d$  - centripetal force,  $Q_k$  - vertical load of a wheel,  $R_{By}$  - component of the vertical load,  $R_{Bx}$  - component of the horizontal load,  $P_h$  - braking force,  $\mu$  - coefficient of friction between the tire and the road,  $\delta$  - inclination of steering pivot (kingpin).

Using the above relations the forces acting on the control arm were calculated. They are respectively: the longitudinal force  $R_{Bx} = 10kN$  and the lateral force  $R_{By} = 6kN$ . The most unfavorable load condition appears during the joint action of both forces occurring during braking in the road arc.

## 2. The Concept of the Composite Control Arm

Table 1. The basic properties of the epoxy matrix and epoxy composites [4]

Material	Compression modulus E [GPa]	Tensile strength $R_m$ [GPa]
Epoxy matrix	4	0,1
Composite reinforced with carbon fibers	253	4,5
Composite reinforced with aramid fibers	124	3,6
Composite reinforced with glass fibers	86	4,5

Taking into account the experience of other researchers [1,2,3,5] as well as our own one related to the construction

of the composite suspension components, the execution of the control arm of the carbon epoxy composite or the glass-epoxy composite was considered. Table 1 shows the fundamental physical properties of composites offered by Hexcel Corp. Definitely, the best parameters has the carbon-epoxy composite. It is characterized by the high stiffness and the good ratio of the strength to the weight. These characteristics have decided on its election as the material to the construction of the arm.

The scope of cloths offered by Hexel [4] company have great potential for the formation of the composite strength properties and the element itself. The company recommends the use of cloth types IM, HM UHM for structures carrying heavy loads, e.g. in the automotive and aerospace industries. However, the fibers of the AS group are recommended by the company to build parts or components less competent, such as the elements of the body panels of cars, boats, etc. Selection of the types of fibers and their arrangement in relation to the directions of stresses is crucial for the strength and durability of the composite. Finally, the carbon-epoxy composite reinforced with fibers type of IM7 Hexcel was used for the construction of the composite control arm. The material provides the high strength and stiffness. The use of the reinforcements of higher modules eg.: IM9 or IM10 leads to a significant increase in material costs with a slight reduction in weight of the element. The selected properties of the epoxy composite on the basis of IM7 fibers are shown in Table 2. The strength analyses were performed using these values.

Table 2. The basic properties of epoxy composite with IM7 fibers [4]

L.p.	Property	IM7 12k
1.	Tensile Strength	2723 MPa
2.	0° Tensile Modulus	164 GPa
3.	0° Tensile Strain	1.6%
4.	0° Short Beam Shear Strength	128 MPa
5.	0° Compressive Strength	1793 MPa
6.	0° Compressive Modulus	150 GPa

The composite control arm was shaped so as not to exceed the dimensions of the steel control arm. The limit dimensions of the control arm in the horizontal plane are shown in Figure 4.

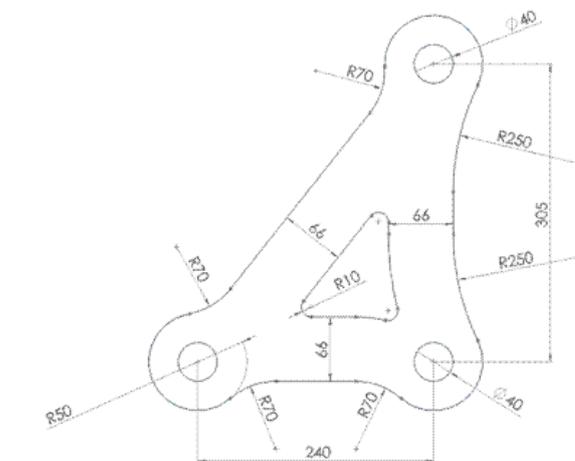


Figure 4. MacPherson Suspension: 1-column, 2-lower control arm, 3-wheel disk

### 3. The Control Arm Strength Analysis

The composite control arm was modeled while maintaining the shape and dimensions of the steel control arm. The number of layers and the orientation of the reinforcement were selected following the criterion of maximum allowable stresses and strains. The analysis was performed by MES method in SolidWorks Premium software using a composite module. The program offers the opportunity to analyze the stresses and displacements of the whole structure and each composite layer separately. The analysis was performed for the loads acting on the control arm during braking, acting of the maximum lateral forces and the simultaneous action of lateral forces and braking forces (1, 2, 3, 4, 6).

#### 3.1. Load of the Control Arm During Vehicle Braking

A preliminary analysis was carried out for the control arm load derived from the maximum braking force. The object was characterized as a composite shell. The layers of cloth were arranged in orientation  $0^\circ$ ,  $90^\circ$ . It was initially assumed that the control arm will be built with 10 uniform layers of the carbon cloth type IM7 Hexcel. The grid was concentrated to the maximum level available in the software (Figure 5).

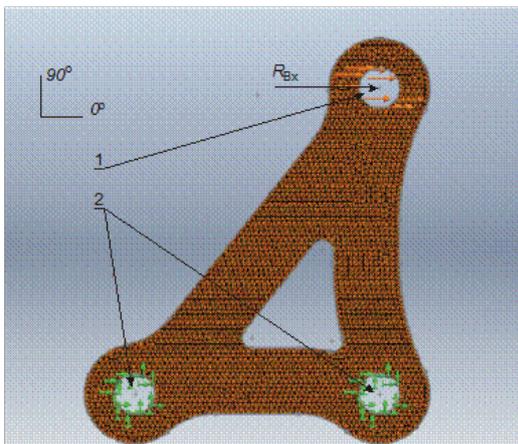


Figure 5. Grid of the composite control arm model. 1- mounting hole of steering pivot, 2 – mounting holes of arm to vehicle body

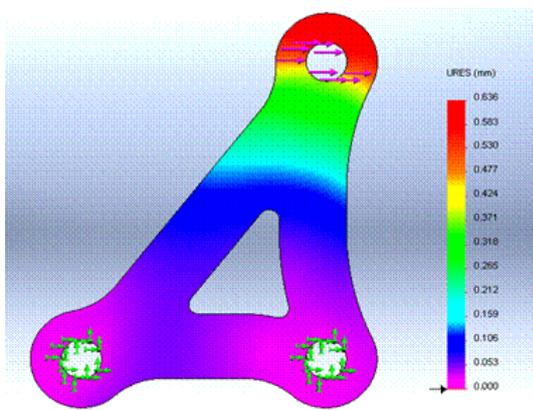


Figure 6. Distribution of displacements of the control arm points during braking

The manufacturer of cloths recommends the use of safety factors in the range from 8 to 10. After preliminary

analyses ten layers reinforcing the arm were used. The layers were positioned so that the top of the subsequent ones alternately formed an angle of  $90^\circ$  and  $52^\circ$  to the axis of mounting holes of the arm to the body. In order to reduce the risk of delamination of the structure near the mounting holes of pins the local reinforcement inserts were used. In this way the element stiffness can be shaped while maintaining operational and strength parameters. For so designed the control arm, the stresses acting within various layers were determined. In each layer the required factor of safety was obtained. The global stresses distribution for the whole arm is shown in Figure 7 and the distribution of displacements in Figure 6.

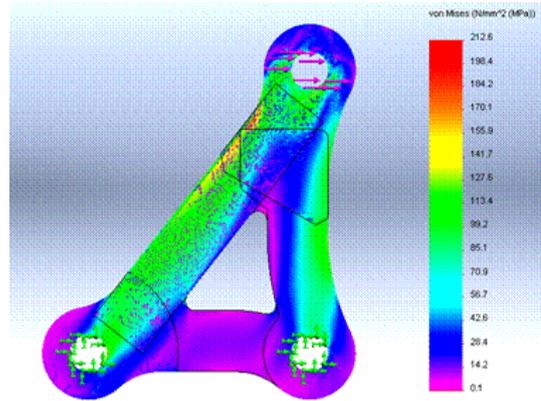


Figure 7. Distribution of stresses in the control arm during braking

The arm pin moves about 0.5 mm and stresses do not exceed 290 MPa. Thus, the values of stresses and displacements are at the proper level because of the strength of the structure and the operating characteristics of the suspension.

#### 3.2. Load of the Control Arm During Braking a Vehicle On The Road Arc

During braking a vehicle while driving on the road arc the control arm is loaded with the braking force and the force of lateral adhesion of a wheel. The control arm of the wheel riding on the outside of the road arc is compressed and bent while the one riding on the inner side is stretched and bent. The loads can be calculated from the relations (1, 2, 3 and 4). Figure 8 and Figure 9 present the distribution of stresses and displacements of the control arm of the outside wheel.

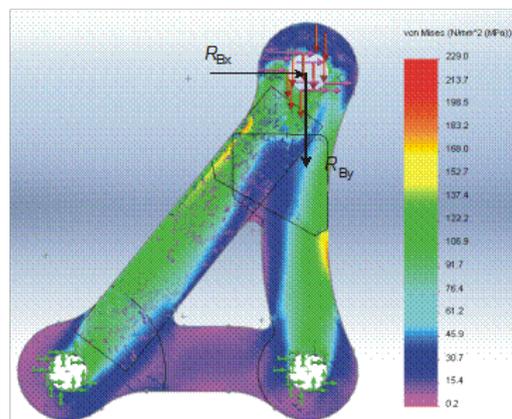
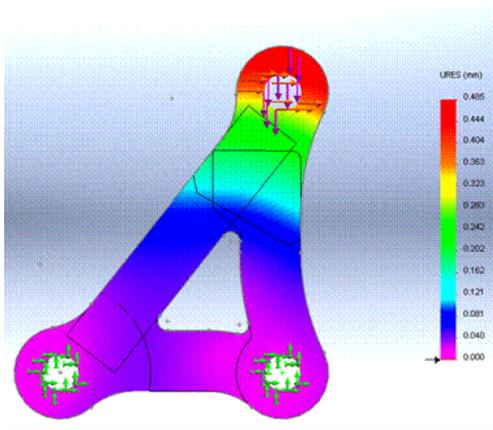
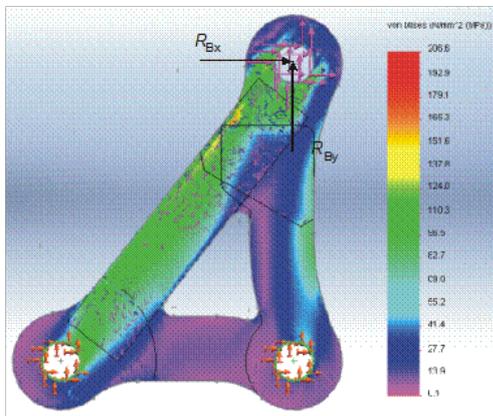


Figure 8. Stresses in the control arm of the outer wheel while driving on the road arc and braking

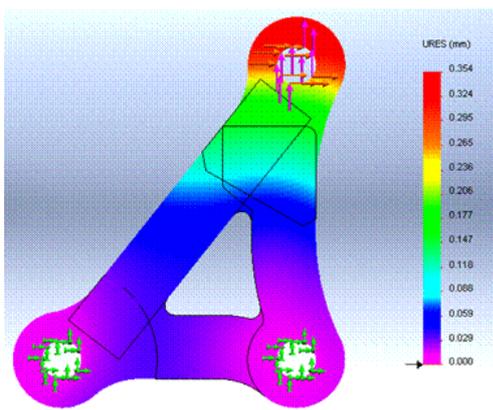


**Figure 9.** Distribution of displacements of the control arm points of the outer wheel while driving on the road arc and braking

Figure 10 and Figure 11 present the distribution of stresses and displacements in the control arm of the inner wheel.



**Figure 10.** Stresses in the control arm of the inner wheel while driving on the road arc and braking



**Figure 11.** Distribution of displacements of the inner wheel control arm while driving on the road arc and braking

The maximum displacement of the axis of the kingpin (steering pivot) does not exceed 0.35 mm which is an acceptable value. The composite control arm is stable and resistant to cracking. The method of mounting joints to the composite structure should be the subject of additional analysis. It is possible to mount them with steel sockets which can be glued, screwed or riveted to the control arm construction.

## 4. Recapitulation

The paper presents the theoretical discussion on the possibility of replacing the actual design of the steel control arm of the car produced today by the structure made of polymer composite. Today exist the solutions of the whole suspension using composite materials and it is justified by the synergy effects possible to obtain. These solutions are characterized by smaller unsprung masses and higher damping coefficients. However, the simply attempts to replace the steel structures by the composite ones are not met. In this paper such an attempt has been undertaken. The steel control arm was replaced by the carbon composite one. The preliminary analysis has shown that such possibility exists. Subsequently, the works initiated will allow for practical verification the designed construction by laboratory tests. In the case of significant improvement in the performance of vehicles containing the composite elements of suspension, the interest of the automotive companies to implement the proposed structure into commercial vehicles is possible.

The works initiated fit into the global trend of construction of the energy-saving lighter vehicles with better functional properties.

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