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QUANTITATIVE METHODS FOR STEERING KNUCKLE MATERIAL SELECTION

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RESEARCH ARTICLE

ABSTRACT: The paper gives a description of the material selection process for a steering knuckle of a passenger vehicle's independent suspension system, by using two quantitative methods of material selection: Weighted Property Method and Limits on Property Method. After the definition of property requirements that potential materials must meet, digital-logic method has been applied in order to calculate the weighting factors of said properties. The material selection process included the application of Cambridge Engineering Selector for the analysis of diagrams and property values of potential materials. The obtained results indicate that the Weighted Property Method leads to the conclusion that the optimal steering knuckle material is low alloy steel 25CrMo4, while the Limits on Property Method shows that aluminum alloy AlZn5.5MgCu T6 is the optimal material.

KEY WORDS: selection, material, steering knuckle, quantitative methods, independent suspension, CES

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KVANTITATIVNE METODE IZBORA MATERIJALA RUKAVCA

REZIME: Rad predstavlja opis postupka izbora materijala rukavca nezavisnog sistema oslanjanja putničkog vozila pomoću dve kvantitativne metode izbora materijala: metode uticajnosti svojstava i metode graničnih vrednosti svojstava. Nakon definisanja osnovnih kriterijuma, tj. zahteva koje potencijalni materijali moraju ispuniti, za računanje faktora važnosti svojstava je primenjena digitalno-logička metoda. Postupak izbora materijala obuhvatao je primenu softvera *Cambridge Engineering Selector* za analizu dijagrama i vrednosti svojstava potencijalnih materijala. Dobijeni rezultati ukazuju da metoda uticajnosti svojstava dovodi do zaključka da je optimalni materijal rukavca niskolegirani čelik 25CrMo4, dok metoda graničnih svojstava materijala pokazuje da je legura aluminijuma AlZn5.5MgCu T6 optimalni materijal.

KLJUČNE REČI: izbor, materijal, rukavac, kvantitativne metode, nezavisno oslanjanje, CES

QUANTITATIVE METHODS FOR STEERING KNUCKLE MATERIAL SELECTION

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INTRODUCTION

Material selection is one of the most important activities in the design process of components of any technical system [1]. The fact that there are more than 70.000 types of materials [2], of which more that 40.000 are metal-based alloys [3] makes the material selection extremely challenging. A large number of available materials, as well as a large number of criteria in the material selection lead to an increase in the complexity and uncertainty in decision making, so it is useful to use quantitative methods [4]. The goal of quantitative methods for material selection is not to replace experience, but to avoid exclusion of some possibilities, as well as to reduce the subjectivity of the process [1]. The material selection started by the ranking the properties of steering knuckle candidate materials depending on the weighting factors, obtained by the digital-logic method. After that, by applying two quantitative methods for material selection, Weighted Property Method and Limits on Property Method, the optimal materials for the steering knuckle of the passenger vehicle's independent suspension system were selected.

1. ENVIRONMENTAL ASPECTS OF THE KZS PROJECT

The suspension system of a passenger vehicle has two basic functions: to maintain the desired position of the wheels in relation to the road surface and the vehicle body, and to receive and transmit generated forces and torques [5]. It is necessary that the suspension system ensures that all four wheels, especially the drive wheels, maintain contact with road surface in all driving conditions. It is of great importance that the suspension system contributes to the decrease of road bumps impact on vehicle, throughout the entire range of vehicle's gear ratios and velocities. Road holding and comfort are essentially opposite requirements, so a compromise between them needs to be reached. There are two types of vehicle suspension systems: dependent and independent. The wheels of the dependent suspension system are placed on a rigid axle, which leads to the direct transmission of the disturbances between the wheels of such an axle, which is undesired. The positive side of this type of suspension system is the constant position of the wheels relative to the road surface. A big disadvantage is large unsprung mass, especially with the drive axle, as well as the relatively large space required for the system mounting. The independent suspension system, unlike the dependent one, allows vertical displacements of a wheel, without it affecting the other wheel of the same axle [7]. Most passenger cars and light trucks are equipped with an independent suspension system on the front axle, as it provides significantly more space for the engine mounting, greater wheel movement, increased vibration resistance, better vehicle handling, and overall better driving comfort. The disadvantage of this system is the complexity of the construction and high production costs, due to the increased number of parts [8, 9]. There are several designs of independent suspension system, of which the most widely used is the system with two control arms of different lengths (Double Wishbone Independent Suspension), shown in Figure 1. The design of the system allows compensation of vehicle body tilting, and keeps the wheels in constant positions relative to the road surface, and provides high vehicle stability [5].

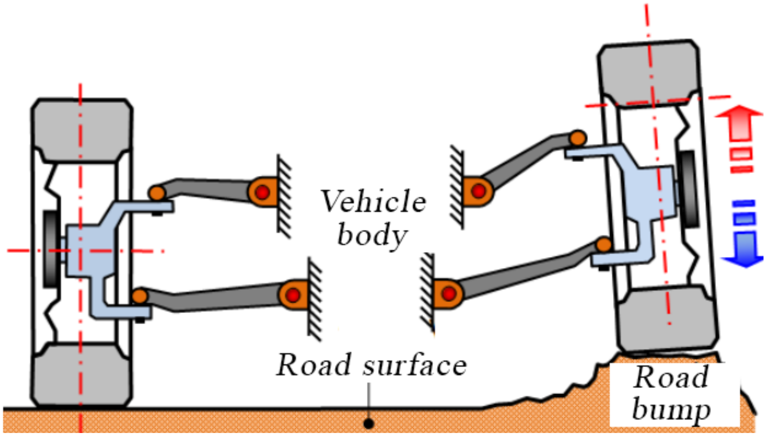

Figure 1 Double Wishbone Independent Suspension [8]

The upper control arms are generally shorter than the lower ones, which directly affects the camber angle values. These suspension systems are commonly known as SLA (Short Long Arms) suspension systems. Control arms are connected to the steering knuckles via ball joints, and to the vehicle body via bushings. Steering knuckle (Figure 2) is one of the most important components of an independent suspension system, and it must be able to withstand loads acting in several directions [10]. These loads include forces due to steering, lateral and longitudinal forces, braking force, inertial force, etc. The steering knuckle provides a link between wheels and the steering system, supports wheel hub and brake caliper, and must provide needed geometrical parameters of drive wheels (camber angle, caster angle, toe pattern, toll center height, scrub radius, turning radius).

Figure 2 Appearance of steering knuckle [11]

Forces and moments present in the vertical loading planes lead to the generation of bending moment in the steering knuckle, while wheel steering and turning lead to torsion moment occurrence. The most advantageous steering knuckle design is the one where the knuckle has a shape of a wheel hub flange, with curved extensions that provide the connection with the ball joints, which accept different working loads, and transfer them to the control arms and tie rod [5]. Steering knuckle can be manufactured by forging, casting or thyxoforming. Taking into account the existing solutions, the influence of characteristics of the mentioned technologies on the geometric accuracy, surface quality, visual appearance and price, it is determined that hot forging is the most favorable manufacturing technology.

2. STEERING KNUCKLE MATERIALS

2.1 Low-carbon steels

Low-carbon steels are very suitable for forging and are relatively low cost, and therefore are commonly used for the manufacturing of some independent suspension system components, such as steering knuckles. The tensile strength of low-carbon steels is not at a very high level, but the ease of forging and low price lead to their wide application.

2.2 Medium-carbon steels

Medium-carbon steels (from 0,3 to 0,5%) are, as a rule, subjected to heat treatment, which reduces residual stresses and improves their ductility. Annealing of medium-carbon steels results in an increase in yield strength and ductility, with a slight decrease in tensile strength and hardness [15].

2.3 Low-alloy steels

Low-alloy steels have better tensile properties compared to low-carbon and medium-carbon steels. Low-alloy steels in which the main alloying elements are chromium and molybdenum (1% Cr; 0,2% Mo) are widely used in the manufacturing of independent suspension system's components. Chromium alloying is usually done in order to increase corrosion and oxidation resistance, as well as to improve hardenability [16]. Molybdenum alloying up to 0,2% further increases the hardenability of low-alloy steels [17]. Another advantage of Cr-Mo low-alloy steels are good creep characteristics [16].

2.4 Aluminum alloys

Aluminum alloys are used for the production of the components of independent suspension systems primarily for the mass savings that they provide [18]. It is estimated that every 10% savings in vehicle mass leads to a reduction in fuel consumption of 5 to 7% [19]. Reduction of vehicle mass results in decrease of gyroscopic torque, which occurs as a result of simultaneous wheel rotation and turning, and has a negative impact on the vehicle handling characteristics [19]. In addition, the usage of aluminum alloy in fabrication of independent suspension system parts leads to high reliability [20], efficient vibration damping, as well as reduction of vehicle noise, compared to other materials which are used to fabricate the components of an independent suspension system. According to the method of processing, aluminum alloys are divided into casting aluminum alloys and wrought aluminum alloys. They can also be divided into aluminum alloys that can be heat treated, and those that cannot be heat treated. The processing of wrought aluminum alloys is performed by forging on mechanical presses, and the blanks are preheated to temperatures of 400-500 °C.

2.5 Magnesium alloys

Of all the materials used to make the vehicle's independent suspension components, magnesium alloys have the lowest density, 1.74 g/cm3, which makes them 35% lighter than aluminum alloys, and over four times lighter than steel [21]. Magnesium alloys are characterized by good ductility, better noise and vibration damping characteristics compared to aluminum alloys, and excellent casting capabilities [22]. The biggest disadvantage of magnesium alloys is their high cost [23]. However, if the reduction in fuel consumption is taken into account, as well as the lower life cycle costs of components made of magnesium alloys compared to other applied metals [24], exploring the possibility of wider implementation has potential. Another disadvantage of magnesium alloys are poor creep characteristics, which can be removed by using Mg-Al-Si alloys, but casting of these alloys is problematic [25].

3. STEERING KNUCKLE MATERIAL SELECTION

The material selection for the steering knuckle will be made for the case of a medium class passenger vehicle, with a curb weight of approximately 1.500 kg, in which a Double Wishbone Suspension can be used on both the front and rear axle, depending on the vehicle drive concept. In order to compare the results of the usage of two different quantitative methods of material selection, the following methods are applied: Weighted Property Method and Limits on Property Method.

3.1 Weighted Property Method

The Weighted Property Method is of special importance when it is necessary to evaluate a large number of component properties. It consists of essential properties consideration, multiplication of their numerical values by the appropriate Weighting Factor (Bi), which leads to the relative importance of each individual property. By summarizing the properties of materials this way, Performance Index (Vr) of each potential material can be calculated. Determination of Weighting Factor of properties is often greatly influenced by experience, so digital-logic method is applied. By using this method, each property is compared with each, property with a greater importance is given the grade 1, and property with less importance is given the grade 0. For n material requirements (properties), the total number of questions is $n \cdot (n-1)/2$. The Weighting Factor is equal to the ratio of the number of positive decisions for the observed property and the total number of questions [26]. The requirements that need to be met during the steering knuckle material selection are:

1. Maximum flexural strength (σ), which reduces the possibility of fractures of the tie rod-connecting region of the steering knuckle.
2. Maximum elongation (A), which provides a high level of material toughness.
3. Maximum modulus of elasticity (E), because it provides a high level of rigidity, which ensures the transfer of forces and moments without significant deformation.
4. Minimum density (ρ), because it leads to minimization of mass, which is one of the main influencing factors on vehicle fuel consumption.
5. Maximum forgeability (F), because it is determined that hot forging is the desired manufacturing technology. The reason for the choice of forging is mainly greater resistance to cyclic plastic deformations of forged steering knuckles compared to cast ones [27], as well as constant and higher fatigue strength of forged steering knuckles throughout service life, again in comparison with cast ones [27].

6. The minimum price per unit volume (C/m3), in addition to technical criteria, directly defines the competitiveness of products on the market.

Since the number of observed properties is n=6, the total number of questions is 15. The results of the digital-logic method for the steering knuckle material are given in Table 1.

Table 1 *Digital-logic method for the steering knuckle material*

Property	Decision														
σ	1	1	1	0	0										
A	0					1	1	0	0						
E		0				0				0	0	1			
ρ			0				0			1			1	1	
F				1				1			1		0		
C/m^3					1				1			0		0	0

Table 2 shows the calculated values of Weighting Factors for the steering knuckle material properties.

Table 2 *Weighting Factors for the steering knuckle material properties*

Property	Positive decisions (1)	Negative decisions (0)
σ	3	0,20
A	2	0,13
E	1	0,07
ρ	3	0,20
F	4	0,27
C/m^3	2	0,13
Total	15	1,00

In case there are a relatively large number of requirements (properties), with different units of measure, it is necessary to introduce the notion of scaled values of properties (Sv), which make it possible to convert dimensional values into dimensionless values [1]. Depending on the nature of the requirement associated with the observed property, the best value may be the maximum or minimum value in the list [3]. When it comes to the steering knuckle, the minimum values of density and price are required, while in the case of flexural strength, elongation, modulus of elasticity, and forgeability, the maximum values of properties are the required ones. When it is difficult to quantify a property value (i.e. forgeability), the considered property is assigned a value from 1 to 5 [4].

If the minimum value of the property is the best, the expression for the scaled value for a given candidate material is [28]:

$$S_{v_i} = \frac{\text{Numerical value of property}}{\text{Maximum value in the list}} \times 100 \qquad (1)$$

and if the maximum value is required from the property, the expression for the scaled value for a given material is [28]:

$$S_{v_i} = \frac{\text{Minimum value in the list}}{\text{Numerical value of property}} \times 100 \qquad (2)$$

The Performance index Vr is used for the ranking of potential materials, and it is expressed as [29]:

$$\mathrm{V_r} = \sum_{i=1}^{n} \mathrm{B_i} \cdot \mathrm{S_{v_i}} \rightarrow \max \qquad (3)$$

Among the low-carbon steels, steel S270GP, which is characterized by good machinability [15], superior deformability compared to other low-carbon steels [30], as well as low price, was selected. Among the medium-carbon steel, C35 steel was chosen, because it is highly forgeable and has been used in the automotive industry for many years to make components of an independent vehicle suspension system [30]. As an ideal material from the group of low-alloy steels, steel 25CrMo4, which is characterized by good tensile and fatigue characteristics, as well as high impact resistance [15], was chosen. Al-Zn-Mg-Cu aluminum alloys were taken into account, due to the favorable combination of strength and susceptibility to heat treatment [31]. Among them, the AlZn5.5MgCu was chosen due to its good tensile characteristics, low density and high corrosion resistance [31]. Heat treatment of this alloy within the T6 regime leads to a significant improvement of its mechanical characteristics [31]. When it comes to magnesium alloys, the most suitable are Mg-Al-Zn alloys, among which the MgAl8Zn, heat treated within the T5 regime was selected. T5 heat treatment regime results in the highest possible strengthening of said alloy [31]. The mentioned alloy is characterized by better tensile characteristics than other Mg-Al-Zn alloys, as well as excellent corrosion resistance [31]. Based on the values of the properties of candidate materials for steering knuckle (table 3), acquired from the Cambridge Engineering Selector (CES) software, which uses data from manufacturers, textbooks, websites, standards, as well as various databases and expert systems, corresponding Performance Indexes were calculated (table 4).

Table 3 *Properties of candidate materials for steering knuckle*

Material	Property					
	σ	A	E	ρ	F	C/m^3
S270GP	274	30	210	7,85	4	3,61
C35	320	27	210	7,85	5	3,69
25CrMo4	400	28	210	7,85	5	3,77
AlZn5.5MgCu T6	500	8	73	2,81	4	6,24
MgAl8Zn T5	205	6	45	1,80	5	5,58

Table 4 *Performance Indexes of candidate materials for steering knuckle*

Material group	Material	Vr	Rank
Low-carbon steel	S270GP[1]	70,2	3
Medium-carbon steel	C35[1]	75,8	2
Low-alloy steel	25CrMo4[1]	79,1	1
Aluminum alloy	AlZn5.5MgCu[2] T6	67,7	4
Magnesium alloy	MgAl8Zn[3] T5	67,6	5

The highest value of Performance Index has low-alloy steel 25CrMo4, hardened at a temperature of 865 °C, and medium-carbon steel C35, in the annealed state. They are followed by annealed low-carbon steel S270GP, aluminum alloy AlZn5.5MgCu T6 and magnesium alloy MgAl8Zn T5. Based on this, it follows that by using the Weighted Property Method low-alloy steel 25CrMo4, hardened at a temperature of 865 °C, is chosen as the material for the steering knuckle of the independent suspension system. The mentioned material is characterized by a good combination of strength, ductility and fatigue strength. The recommended forging temperature of this steel is 1205 °C [33].

3.2 Limits on Property Method

Limits on Property Method quantitative method of material selection is based on the mapping of the material requirements into the limit values of material properties, more precisely: lower-limit values of properties, upper-limit values of properties and target values of properties [34]. Whether a lower-limit, upper-limit or target value will be set for a certain property depends on the requirements posed on a certain property [34]. Within the Limits on Property Method, a quantitative comparison of materials is performed according to the value of the Figure of Merit M, for each of the candidate materials, according to the expression [34]:

$$M = \left[\sum_{i=1}^{n_d} B_i \frac{Y_i}{X_i}\right]_d \cdot \left[\sum_{j=1}^{n_g} B_j \frac{X_j}{Y_j}\right]_g \cdot \left[\sum_{k=1}^{n_c} B_i \left|\left(\frac{Y_k}{X_k}\right) - 1\right|\right]_c \rightarrow \min \qquad (4)$$

where:

- d, g and c are the lower-limit, upper-limit, and target value properties, respectively.
- n_d, n_g and n_c are the numbers of lower-limit, upper-limit, and target value properties, respectively.
- B_i, B_j and B_k are the weighting factors for the lower-limit, upper-limit, and target value properties, respectively.
- X_i, X_j and X_k are the candidate material lower-limit, upper-limit, and target value properties, respectively.

[1] *Designation accoring to standard EN10025:2019.*
[2] *Designation accoring to standard EN 573-2:1994.*
[3] *Designation accoring to standard ISO 3116:2019.*

- Y_i, Y_j and Y_k are the specified lower limits, upper limits, and target values, respectively.

Table 5 shows the Limit Values of properties, as well as Weighting Factors of the properties for the steering knuckle candidate materials, which were calculated in the previous part of the paper, by using the digital-logic method.

Table 5 *Limit values and weighting values of candidate materials for steering knuckle*

Property	Limit value	Weighting factor Bi
σ	Lower Yi = 200 [MPa]	0,20
A	Target Yk = 15 [%]	0,13
E	Lower Yi = 45 [GPa]	0,06
ρ	Target Yk = 3 [kg/m3]	0,20
F	Target Yk = 5 [-]	0,27
C/m3	Upper Yj = 6,5 [€/m3]	0,13

Based on the Limit Values of the properties, the Figures of Merit of the candidates for the steering knuckle material were calculated, as it is shown in Table 6.

Table 6 *Figures of Merit of candidates for the material of the steering knuckle*

Material	M	Rank
S270GP	0,67	3
C35	0,69	4
25CrMo4	0,66	2
AlZn5.5MgCu T6	0,47	1
MgAl8Zn T5	0,88	5

Limit on Values quantitative method of material selection indicates that the optimal material for the steering knuckle of an independent suspension system is aluminum alloy AlZn5.5MgCu T6.

4. CONCLUSIONS

Making the right decision when in comes to selecting the materials is of great importance during the design process of responsible components. A large number of available materials, as well as a large number of requirements lead to material selection complexity, so it is useful to apply certain quantitative methods of material selection. Within these methods, numerous values of material properties are used in the form of measured or estimated values. The material selection of the independent suspension system of passenger vehicle's steering knuckle was done by applying two quantitative methods of material selection: the Weighted Property Method and the Limits of Property Method. Using the first method, low-alloy steel 25CrMo4 was chosen as the optimal material for the steering knuckle, as the material with the highest value of Performance Index. According to the second method, aluminum alloy AlZn5.5MgCu, heat treated within the T6 regime, was chosen for the steering knuckle material. Based on the comparison of the results of application of different quantitative methods of material selection, it follows that the Limits of Property Method gives preference to aluminum alloys, primarily due to high flexural strength and low density, which are, in addition to forgeability, one of the most important properties of independent suspensions' steering knuckle material.

REFERENCES

[1] Filetin, T.: Izbor materijala pri razvoju proizvoda. Zagreb: Fakultet strojarstva i brodogradnje, 2006.

[2] Ashby, M. F.: Materials Selection in Mechanical Design (4th edition). Oxford, UK: Butterworth Heinemann, 2011.

[3] Farag, M. M.: Materials and Process Selection for Engineering Design (3rd edition). Florida, USA: CRC Press, 2014.

[4] Filetin, T.: Usporedba kvantitativnih metoda izbora materijala. Zbornik radova 4. konferencije iz operacionih istraživanja – KOI 94, Rab, 1994, str. 119–128.

[5] Dedović, V. V.: Nezavisno oslanjanje automobila. Beograd: Saobraćajni fakultet Univerziteta u Beogradu, 1998.

[6] Koulocheris, D. V., Papaioannou, G. D., Christodoulou, D. A.: Assessment of the Optimization Procedure for the Nonlinear Suspension System of a Heavy Vehicle. Mobility & Vehicle Mechanics, 2016, Vol. 42, No. 2, pp. 17–35.

[7] Živković, V., Nedić, B., Đurić, S.: Manufacturing Specificity of Vehicle's Independent Suspension System Parts. Mobility & Vehicle Mechanics, 2020, Vol. 46, No. 1, pp. 31–41, DOI: 10.24874/mvm.2020.46.01.03.

[8] Lajqi, S., Pehan, S., Lajqi, N., Gjelaj, A., Pšeničnik, J., Emin, S.: Design of Independent Suspension Mechanism for a Terrain Vehicle with Four Wheels Drive and Four Wheels Steering. MOTSP 2012 Conference Proceedings, 2012, pp. 230–237.

[9] Kumar, T., Stephen, R., Zaeimi, M., Wheatley, G.: Formula SAE Rear Suspension Design. Mobility & Vehicle Mechanics, 2020, Vol. 46, No. 2, pp. 1–18, DOI: 10.24874/mvm.2020.46.02.01.

[10] Bhokare, K. S., Kakandikar, G. M., Kulkarni, S. S.: Predicting the Fatigue of Steering Knuckle Arm of a Sport Utility Vehicle While Deploying Analytical Techniques Using CAE. International Journal of Scientific Research and Management Studies (IJSRMS), 2013, Volume 1, Issue 11, pp. 372–381.

[11] Hirt, G., Cremer, R., Witulski, T., Tinius, H. C.: Lightweight Near Net Shape Components Produced by Thixoforming. Materials and Design, 1997, Vol. 18, No. 4, pp. 315–321, DOI: 10.1016/S0261-3069(97)00071-X.

[12] Heißing, E.: Chassis Handbook. Berlin, Germany: Springer Science+Business Media, 2011.

[13] European Aluminum Association, The Aluminium Automotive Manual: Applications – Chassis & Suspension – Suspension parts, 2011.

[14] Adams, H.: Chassis Engineering: Chassis Design, Building & Tuning for High Performance Handling. New York, USA: The Berkley Publishing Group, 1993.

[15] Steiner, R.: ASM Handbook Volume 1: Properties and Selection: Irons, Steels and High-Performance Alloys. Ohio, USA: ASM International, 1990.

[16] Semiatin, S. L.: ASM Handbook Volume 14: Forming and Forging. Ohio, USA: ASM International, 1988.

[17] Chen, XR., Zhai, QJ., Dong, H., Dai, BH., Mohrbacher, H.: Molybdenum alloying in cast iron and steel. Advances in Manufacturing, 2019, Volume 8, pp. 3–14, DOI: 10.1007/s40436-019-00282-1.

[18] Belingardi, G., Obradović, J.: Recent Developments in Car Body Lightweight Design – A Contribution Toward Greener Environment. Mobility & Vehicle Mechanics, 2012, Vol. 38, No. 4, pp. 7–23.

[19] Borns, R., Whitacre, D.: Optimizing Designs of Aluminum Suspension Components Using an Integrated Approach. SAE Technical Paper, 2005. DOI: 10.4271/2005-01-1387.

[20] Fukuda, A., Inagaki, Y.: New Applications of Forged Aluminum Suspension Arms. Kobelco Technology Review, 2008, No. 28, pp. 35-38.

[21] Kuo, J.L., Sugiyama, S., Hsiang, S.H., Yanagimoto, J.: Investigating the characteristics of AZ61 Magnesium alloy on the hot and semi-solid compression test. International Journal of Advanced Manufacturing Technology, 2006, Vol 29, Issue 7–8, pp. 670–677, DOI: 10.1007/s00170-005-2560-x.

[22] Jain, C.C., Koo, C.H.: Creep and corrosion properties of the extruded magnesium alloy containing rare earth. Materials Transactions, 2007, Vol. 48, No. 2, pp. 265–272, DOI: 10.2320/matertrans.48.265.

[23] Kulekci, M. K.: Magnesium and its alloys applications in automotive industry. International Journal of Advanced Manufacturing Technology, 2008, Vol. 39, Issue 9-10, pp. 851–865, DOI: 10.1007/s00170-007-1279-2.

[24] Hakamada, M., Furuta, T., Chino, Y., Chen, Y., Kusuda, H., Mabuchi, M.: Life cycle inventory study on magnesium alloy substitution in vehicles. Energy, 2007, Vol. 32, Issue 8, pp. 1352–1360, DOI: 10.1016/j.energy.2006.10.020.

[25] Pekguleryuz, M. O., Baril, E., Labelle, P., Argo, D.: Creep resistant Mg-Al-Sr alloys. Journal of Advanced Materials, 2003, Vol. 35, No 3, pp. 32–38, DOI: 10.1002/adem.200300403.

[26] Dieter, G. E.: Material Selection and Design. Ohio, USA: ASM International, ASM Metals Handbook, 1997, Volume 20.

[27] Zoroufi, M, Fatemi, A.: Fatigue Life Comparisons of Competing Manufacturing Processes: A Study of Steering Knuckle. SAE Technical Paper 2004-01-0628, 2004. doi:10.4271/2004-01-0628.

[28] Murray, G. T.: Handbook of Materials Selection for Engineering Applications. New York, USA: Marcel Dekker, 1997.

[29] Kutz, M.: Handbook of Materials Selection. New York, USA: John Wiley & Sons, 2002.

[30] Cardarelli, F.: Materials Handbook: A Concise Desktop Reference (2nd edition). London, UK: Springer-Verlag London Limited, 2008.

[31] ASM International, ASM Handbook Volume 2: Properties and Selection: Nonferrous Alloys and Special-Purpose Materials. Ohio, USA: ASM International, 1990.

[32] Harper, C. A.: Handbook of Materials for Product Design (3rd edition). New York, USA: McGraw-Hill, 2001.

[33] Semiatin, S. L., ASM Handbook Volume 14: Forming and Forging. Ohio, USA: ASM International, 1988.

[34] Ristić, B., Popović, Z., Adamović, D., Devedžić, G.: Izbor biomaterijala u ortopedskoj hirurgiji. Vojnosanitetski pregled, 2010, Volumen 67, Broj 10, pp. 847–855.