International Journal of Engineering & Technology, 7 (3.17) (2018) 71-75

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Design and Optimization of Front Lower Control Arm (FLCA) for C-Segment Passenger Car

Mohd Hafizi Abdul Rahman[1], Mohd Shukor Salleh[2]*, Mohd Suffian Ab. Razak[1], Mohamad Ridzuan Mohamad Kamal[1], Zolkarnain Marjom[1], Liza Anuar[3] and Nur Adzly Mohamad Saad[3]

[1]Fakulti Teknologi Kejuruteraan, Universiti Teknikal Malaysia Melaka
[2]Fakulti Kejuruteraan Pembuatan, Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[3]Vehicle Development & Engineering, Perusahaan Otomobil Nasional Sdn Bhd
Persiaran Kuala Selangor, Seksyen 26, 40400 Shah Alam, Malaysia
**Corresponding author Email: shukor@utem.edu.my*

Abstract

In this paper, the design optimization and fabrication process of aluminium cast for front lower control arm (FLCA) were investigated. In this work, the new design concept of front lower control arm is employed. CATIA software was employed in this work to design the concept of the lower control arm. After that, Hyperworks software is used to analyze the structural strength and optimized the weight of the part. The target of the new design is 20% reduction of the overall weight of the front lower control arm which fabricated using steel material. The obtained results show a significant reduction of the overall weight as high as 25% with a fatigue life cycle 396,000 cycles. This finding proved that the new design of front lower arm has fulfilled the criteria of fatigue life cycle and suitable to be used in a C-segment passenger car.

Keywords: *Design, Topology optimization, Aluminum cast, lower control arm*

1. Introduction

Several factors such as global warming, increase of energy prices, emission and many more factors that influence the automotive manufacturer to design the lightweight vehicle [1].The challenge for automotive manufacturer to produce the lightweight components but at the same time need to maintain the performance of the components. To produce the lightweight components, the main criteria to overlook are the advance material and the manufacturing technology. Weight reduction enables the manufacturer to develop the same vehicle. If all the components in vehicle can contributed for about 10% to 20% of weight reduction, it is estimated that 20% of vehicle weight reduction results in 8–10% of fuel economy improvement. There several ways to achieve the lightweight components in vehicle. Changing a new lightweight material such as composites and aluminum alloy can give a good weight reduction to vehicle and improve the fuel economy[2]. Nowadays, several automotive manufacturers already change from steel alloy and cast iron to alternative lightweight material such as composite and aluminum alloy. The market pattern for material show gradual decrease for steel and cast-iron usage in automotive industries.

Nowadays, aluminum alloy are widely used in automotive sectors in order to give lightweight vehicle and improve fuel efficiency [3]. Ford as one of the automotive manufacturer widely used the aluminum alloy in body in white (BIW) structure and closure such as panel door outer, roof, panel hood outer, trunk lid, tailgate, etc. For examples, Ford F150 model 2015 mostly used Aluminum alloy for the body in white structures and at the closure panels. Meanwhile, the Cadillac ATS and CT6 used mixing material such as using aluminum casting, high strength steels and sheet metals on their BIW and closures panels [4].

There are two type of aluminum alloy that widely used in automotive industries. The first type non-heat-treatable and the second type is work-hardening of aluminum alloy. The type non-heat-treatable aluminum alloy such as AlMg(Mn) alloys (5000 series alloys) shows the good combination of strength and formability. Then for the work-hardening aluminum alloy type, AlMgSi alloys (6000 & 7000 series alloys) obtain the required strength through the heat treatment cycle [5].

Most of the chassis components in vehicle that use aluminum alloy commonly use that non heat-treatable type for series 5000 because its showed good formability and weldability. However aluminum alloys that exposed to the heat treatment process can resist from the corrosion to occurred [6]. Moreover, cast aluminum alloys (i.e A319, Adc 12 and A356) is used widely to fabricate an engine component such as flywheel, cap cam shaft and engine mounting.

Focusing in the front suspension assembly, there are several parts involved such as lower control, spring, damper, knuckle and tie rod. In this study, the components that has been done for the weight reduction is front lower control (FLCA). The front lower control arm is a part connected between subframe and knuckle. Function of front lower control arm is to control the alignment of wheel and to con-

trol the lateral and longitudinal loading transmitted from wheel to the suspension subframe. Major role of front lower control. So front lower control arm need a robust design to sustain higher loading in front suspension but at the same time need a lighter weight to give the optimum performance as the main alignment [7-8].
Commonly, steel material is used to fabricate the lower control arm [8]. The weight of this part is about 4.8 Kg. Hence, there is a needs to reduce the weight of the part as to fulfill the car manufacturer's target to reduce the fuel consumption of their vehicle [10-11]. Therefore, a new design of lower control arm which utilized cast aluminum alloys is needed to reduce the weight of the parts as much as 20%. Up to date, there is no design that identical to the proposed design as it utilized the I-beam concept to reduce the weight of the part. Design of the aluminum cast lower arm was carried out in combination of finite element (FE) analysis and design optimization process. There are two types of optimization method. The first type is topology optimization and the second type are shape optimization that normally used in optimization process of new product. In this research, topology optimization is used since the topology optimization process able to optimize with predefined constraint such as loading at all bush mounting compared to shape optimization. Fatigue analysis is then carried out to analyze the durability and robustness of the new design of front lower control arm. Successful outcome of this new design will contribute to the weight reduction and reduce the fuel consumption especially for C-segment passenger car.

2. Research Methodology

Three main process areas were utilized in this study. There are new design concept, optimization and structural strength and fatigue. The detail process flow chart shown in Figure 1 below:

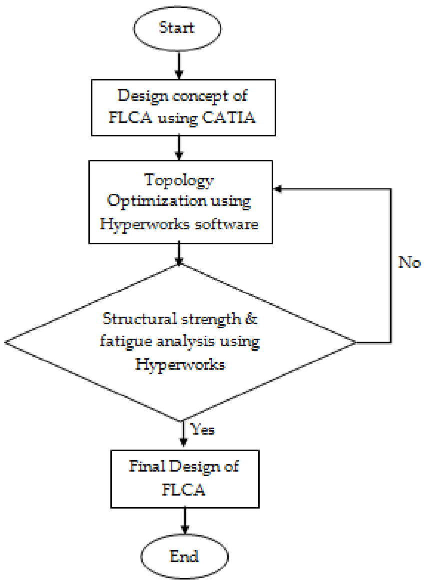

Fig. 1: Process flow chart of design optimization of aluminum cast FLCA

2.1. Design Concept of Aluminium Cast Lower Control Arm

The initial conceptual design of FLCA starts with a solid design to get the basic shape based on current stamping FLCA using CATIA V5 as shown in Figure 2. The general L-shape of current metal stamping front lower control is remained to avoid any major changes to the surrounding parts, the hardpoints of lower control arm and to endure the same kinematics performance of lower control arm.

Fig. 2: Current metal stamping (a) and initial concept design (b) of front lower control arm

The initial concept design, then undergo the optimization process and strength analysis to achieve the target 20% of weight reduction for this part. The challenge in the design process after the optimization process is to consider the casting process and the clearance issue with the surrounding parts in the suspension system.

2.2. Topology Optimization of Design Concept

In topology optimization process using Hyperworks Optistruct software, the base concept design was optimized based on standard suspension abusive loadcases loading at FLCA hardpoint as shown in Table 1. The topology optimization is a method to optimize the design in design space with the constraint of loads and some boundary condition. It is a stress-based optimization through load path on the geometry [10]. It gives the best selection of design based on load path on material to reduce the weight of material. Focusing on FLCA design, the non-load path area based on suspension abusive loading were eliminated to reduce the material. This process was done in several iterations to get the optimum minimum 20% weight reduction target as shown in Figure 3.

Table 1: Suspension Abusive Loadcases

Analysis	Suspension Abusive Loadcases
Linear	Design Position
	Porthole Brake
	Ultimate Vertical
	Reverse Brake
Non-linear	Oblique Kerb Strike
	Lateral Kerb Strike
	Porthole Corner

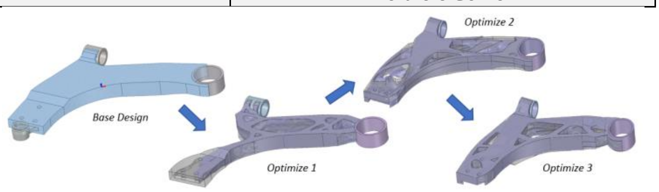

Fig. 3: Topology optimization process of aluminum cast FLCA

2.3. Structural Strength and Fatigue Analysis of Optimize Design Concept

Figure 4 shows the Strength analysis of FLCA based on suspension abusive loadcase. The structural strength analysis of optimized design FLCA is evaluated based on Proton suspension abusive loadcases which is derived from multibody dynamics (MBD) analysis of suspension system. The loading from MBD suspension abusive loadcases will be used to run strength analysis. The Finite Element (FE) model for FLCA design was setup in Altair Hypermesh software. The loading was applied at front bush, rear bush and outer bush mounting. Based on the suspension abusive loadcases, there are four loadcases under linear analysis which are design position, porthole brake, ultimate vertical and reverse brake[13-16]. The strength results based on this four loadcases must not over the yield stress of material which about 235 MPa for aluminum LM25 material. The other three loadcases are oblique kerb strike, lateral kerb strike and porthole corner under non-linear loadcases since it gives higher and severe loading compared to linear loadcases. The non-linear loadcases strength results must not over the Ultimate Tensile Stress (UTS) of aluminum LM25 material which about 250 MPa. All the seven loadcases target safety factor must achieved above 1.2 as per target requirement.

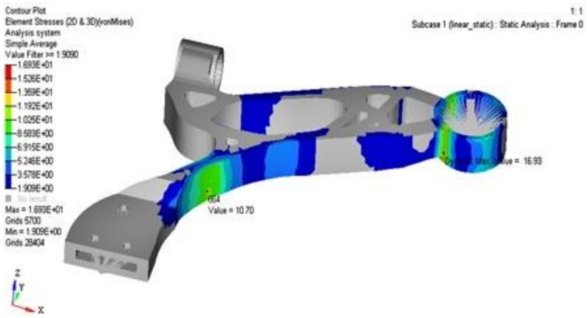

Fig. 4: Structural strength analysis using Hypermesh software

Then fatigue analysis is then carried out using Hyperworks software to analyze the durability and robustness of the new design of front lower control arm. The fatigue test loadcases based on Proton fatigue test standard for front lower control arm. Two type of fatigue test which are longitudinal load and lateral load fatigue test is used in this study. Loading about 9000N were applied at lower control arm outer hardpoint as shown in Figure 5. The part must comply with target 300,000 cycles to pass the fatigue test.

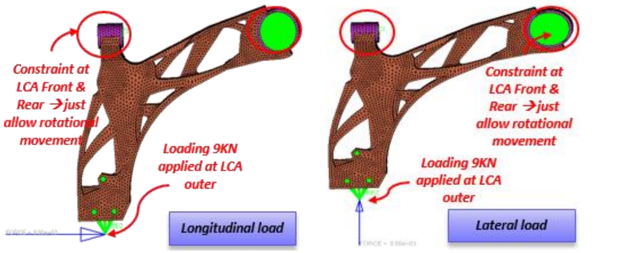

Fig. 5: Longitudinal and lateral fatigue analysis model setup

3. Results and Discussion

3.1. Optimization & Structural Strength Analysis of Aluminium Cast Lower Control Arm

The optimization design of aluminum cast FLCA consists of several iterations to reduce weight up to 20% from the current design. The optimized design based on Proton Suspension Abusive 7 loadcases loading. Loading is applied at FLCA hardpoints (FLCA front, FLCA rear & FLCA outer). After that, all the iteration design will be evaluated. For design iteration 1 based on Figure 6, the optimization process is based on design/static position loadcase only. Based on this iteration, the weight of FLCA can reduce up to 37.53% which is about 2.124 kg. Then the design will be analyzed in term of strength based on loading from suspension abusive loadcase. Based on the strength results for design iteration 1, only two loadcases meet the target safety factor above 1.2 which are design position about 13.88 safety factor as shown in figure 7(a) and ultimate vertical about 3.21 as shown in figure 7(c). The other four loadcases as shown in figure 7 (b), (d), (e), (f) and (g) not meet the target safety factor 1.2 especially on non-linear loadcases such as an oblique kerb strike, lateral kerb strike and porthole corner which give a lower safety factor. So, the FLCA need to re-design to meet the strength requirement.

Fig. 6: FLCA design iteration 1

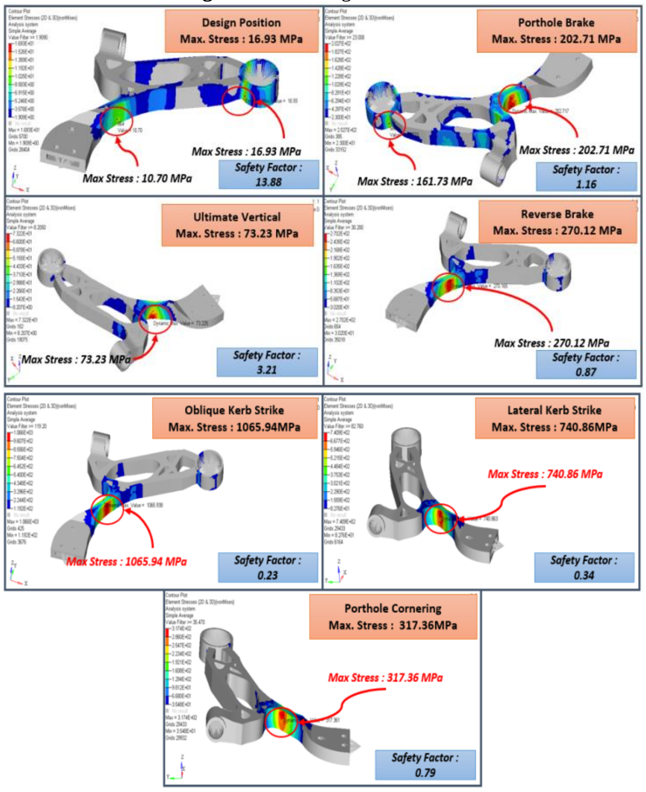

Fig. 7: Structural strength results for design iteration 1

Next, the design iteration 2 as shown in Figure 8(a) covered all 7 loadcases loading. Based on this design, it gives 23.41% of weight reduction which is about 2.604 kg. For design iteration 3 as shown in Figure 8(b), the optimization process is more focusing on a combination of non-linear loadcases that gives higher loading which are oblique kerb strike, porthole brake, porthole corner and lateral kerb strike. Based on this loadcases, the weight reduction is about 26.18%. The strength analysis for design iteration 2 more focusing on non-linear loadcases. The maximum stress occurred for all three non-linear loadcases still below the ultimate tensile strength (UTS) of material. The safety factor loadcases oblique kerb strike, lateral kerb strike and porthole cornering are about 1.59, 6.14 and 12.72 respectively as shown in figure 9(a), (b) and (c). All these 3 loadcases meet the target safety factor above 1.2.

Fig. 8: (a) Design iteration 2 and (b) design iteration 3

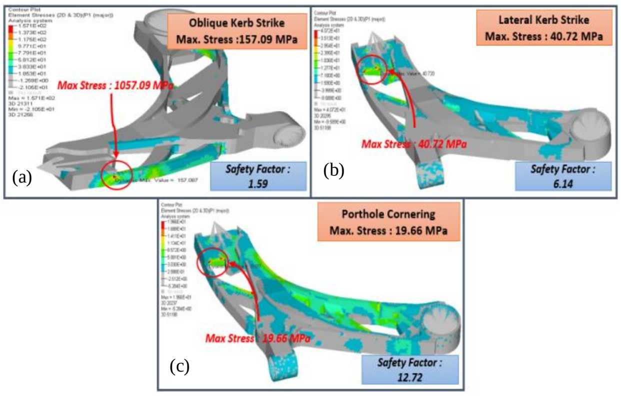

Fig. 9: FLCA design iteration 3 strength non-linear analysis for oblique kerb strike (a), lateral kerb strike (b) and porthole corner (c) loadcases

3.2. Final Design of Aluminium Cast Lower Control Arm

The final design of FLCA is based on the optimized design iteration 3 as shown in Figure 10. This design is more focusing on manufacturing design that tailored for the casting and machining process. The weight for final design achieved 2.55 kg, which about 25.0% weight reduction. Based on this final design, there are constraints to replicate the 100% design as per design iteration 3 due to manufacturing process and a clearance issue with the surrounding suspension parts. The front bush housing needs to replace with adaptable bush as shown in Figure 10 to overcome the clearance issue. Based on design iteration 3, the front bush housing is a part of aluminum cast with thickness 7.5 mm has not met the target clearance above 5 mm with surrounding parts. By reducing the thickness of cast front bush housing will gives lower strength in that area to endure the load at front bush. The best countermeasure for this issue is to apply the adaptable bush using material SAPH 440 with 2 bolted connecting between steel and aluminum cast.

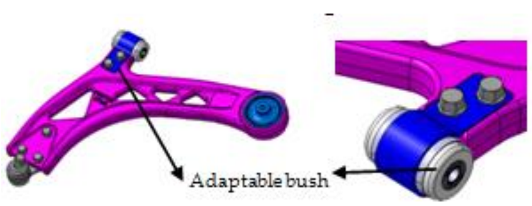

Fig. 10: Final design of aluminium cast FLCA with adaptable bush

The strength analysis was done for final design of FLCA. Based on linear loadcases design position, porthole brake, ultimate vertical and reverse brake, the maximum stress still below from the yield stress of material and the safety factor above 1.2 as shown in figure 11 (a) to (d). same goes to all three non-linear loadcases, the maximum stress occurred below the UTS of material which give higher safety factor as shown in figure 11(e) to (g). Summary of the optimization design for all iteration as shown in Table 2.

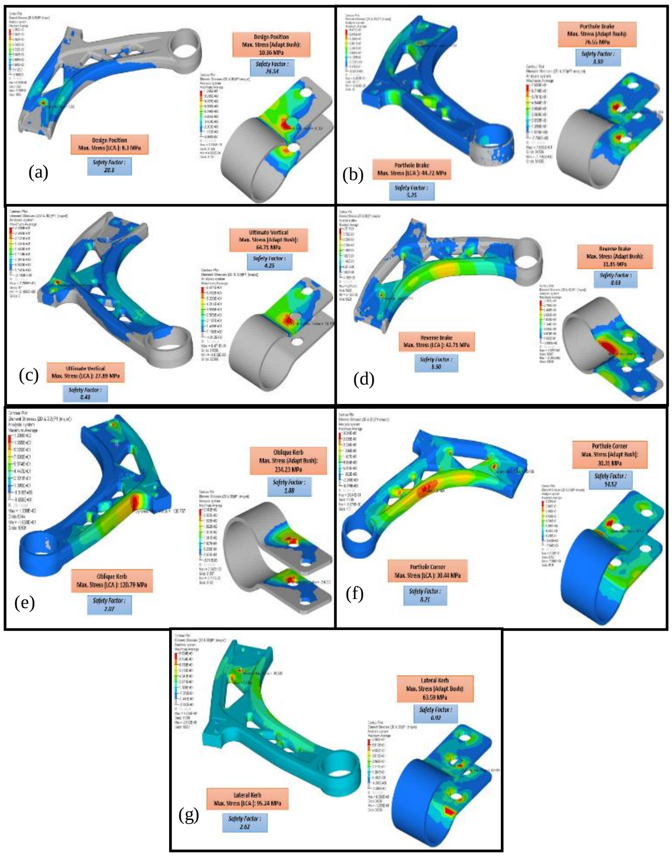

Fig. 11: Structural strength results for final design

Table 2: Summary of design optimization iteration

Optimize Design	Target Weight (kg)	Weight (kg)	% Reduce Weight
Iteration 1	***Min 20% reduce weight (max 2.7kg)***	2.124	37.53%
Iteration 2		2.604	23.41%
Iteration 3		2.510	26.18%
Final Design		2.550	25.00%

The fatigue test analysis was done for final design of FLCA. Based on both lateral and longitudinal loadcases, the aluminum cast of FLCA meets the fatigue test target 300,000 cycles. The longitudinal fatigue test achieved 396,000 cycles and lateral fatigue test achieved 346,000 cycles as shown in Figure 12. Therefore, it is proved that the performance of optimized design cast aluminum alloy of FLCA gives better performance compared to current metal stamping part.

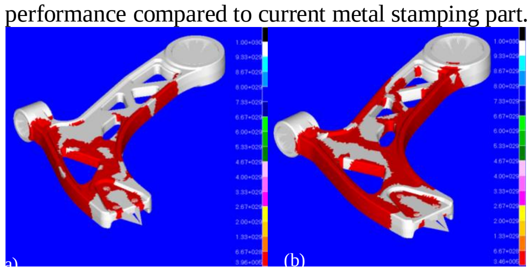

Fig. 12: Longitudinal fatigue test (a) and lateral fatigue test (b) analysis results

3.2. Design Comparison of the commercial lower arm and cast lower arm

The commercial part of FLCA consist of two-piece of metal stamping parts coated with black paint as shown in Figure 13. It was designed as two-piece metal stamping parts lower arm by using welding process. The disadvantage of using a welding process is the part is exposed with the corrosion thus reduce the performance of the part. However, in this work, the new design of aluminum cast front lower control is produced which utilized the aluminum alloys. The alloys used in this part have a corrosion resistance characteristic while it promises the good strength to support the body of the vehicle. By referring to the Figure 14, it has 4 degrees of draft angle at parting lines surrounding the body part. It also has four unique triangular shape holes to minimize the weight. The cross section of lower control arm has I-shaped beam characteristic. Due to its shape, the body part has a high moment of inertia and stiffness which makes it resistant to bending moments. This unique and robust design gives better performance compared to current commercial front lower control arm part.

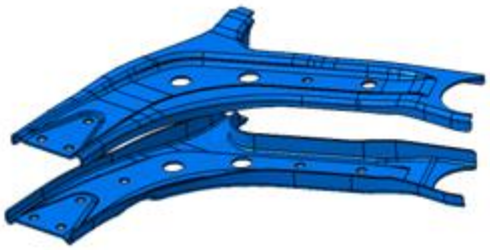

Fig. 13: Two-piece of commercial metal stamping of front lower control arm

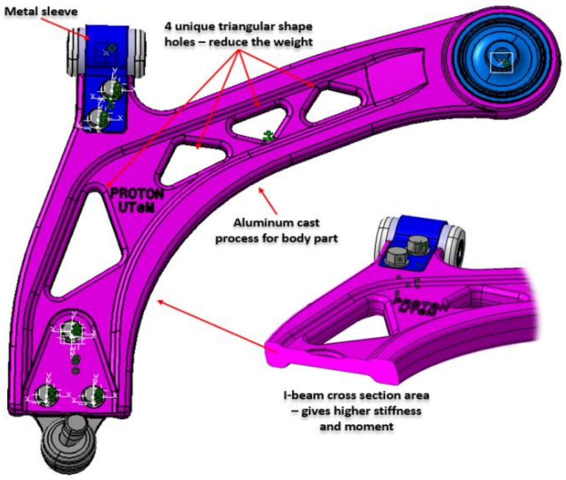

Fig. 14: The new design of aluminum cast front lower control arm

4. Conclusion

The main objective of this research is to design a new lightweight of front lower control arm for the C-Segment vehicle using topology optimization process and new material is introduced which used aluminum cast. This research can be beneficial to the automotive industry and university in term of knowledge transfer, experience and expertise to explore in lightweight material and manufacturing process which focusing on new casting process compared to current conventional stamping process so that the vehicle performance on par with other global Automotive Manufacturer in term of lightweight vehicle and advance manufacturing process.

After several iterations of design and optimization process of aluminum cast FLCA, the weight reduction of aluminum cast FLCA achieved the target of 20% of weight reduction. Based on the final design concept of FLCA, the total weight is 2.55 kg, which is about 25% of weight reduction compared to current metal stamping FLCA weight 3.40 kg and still maintain the structural strength performance and fatigue durability performance.

The new design of this aluminum cast lower control arm has unique design compared to the current commercial design. It has shown some novelty in term of the design shape of the body part with the combination of the aluminum cast for body parts and sleeves metal stamping for at rear lower control arm bush hardpoint. The I-beam cross section gives higher stiffness and a moment for the part to sustain the higher bending moment.

Acknowledgement

The authors would like to thank the Universiti Teknikal Malaysia Melaka and Perusahaan Otomobil Nasional Sdn Bhd (PROTON) for financial support under grant GLuar/PROTON/2016/FKP-AMC/I00006.

References

[1] Ijagbemi CO, Oladapo BI, Campbell HM & Ijagbemi CO (2016), Design and simulation of Fatigue Analysis for a Vehicle Suspension System and its Effect on Global warming - for merge. *Procedia Engineering* 159, 124–132
[2] Asnafi N, Langstedt G, Andersson CH, Östergren N & Håkansson T (2000), New lightweight metal-composite-metal panel for applications in the automotive and other industries. *Thin-Walled Structures* 36, 289–310
[3] Chen JK, Hung HY, Wang CF & Tang NK (2017), Effects of casting and heat treatment processes on the thermal conductivity of an Al-Si-Cu-Fe-Zn alloy. *International Journal of Heat and Mass Transfer* 105, 189–195
[4] Joost WJ & Krajewski PE (2016), Towards magnesium alloys for high-volume automotive applications. *Scripta Materialia* 128, 107–112
[5] Nikoo MF, Azizi H, Parvin N & Naghibi HY (2016), The influence of heat treatment on microstructure and wear properties of friction stir welded AA6061-T6 / Al 2 O 3 nanocomposite joint at four different traveling speed. *Journal of Manufacturing Processes* 22, 90–98
[6] Ju¨rgen Hirsch (2011), Aluminium in Innovative Light-Weight Car Design *. 52, 818–824
[7] Kim Y, Jeong J, Park J, Yang I, Park T, Muhamad PB, Choi D & Oh J (2013), Optimization of the lower arm of a vehicle suspension system for road noise reduction by sensitivity analysis. DOI: 10.1016/j.mechmachtheory.2013.06.010
[8] Zhao LH, Zheng SL & Feng JZ (2014), Failure mode analysis of torsion beam rear suspension under service conditions. *Engineering Failure Analysis* 36, 39–48
[9] Kim DH, Choi DH & Kim HS (2014), Design optimization of a carbon fiber reinforced composite automotive lower arm. *Composites Part B: Engineering* 58, 400–407
[10] Hyun S, Ho S, Choi D & Ho G (2013), Toward a stress-based topology optimization procedure with indirect calculation of internal finite element information. *Computers and Mathematics with Applications* 66, 1065–1081
[11] Vdovin D & Chichekin I (2016), Loads and Stress Analysis Cycle Automation in the Automotive Suspension Development Process. *Procedia Engineering* 150, 1276–1279