International Journal of Natural and Engineering Sciences 9 (2): 34-38, 2015
ISSN: 1307-1149, E-ISSN: 2146-0086, www.nobel.gen.tr

Numerical Analysis of Light Commercial Vehicle Headlamp for Pedestrian Safety

Murat YAZICI[1*] Harun GÜÇLÜ[1] İdris KAREN[2] İbrahim Kürşad KANDIRMIŞ[1] Salim YAGOUP[1] Sertaç MALKOÇ[3]
[1]Department of Automotive Engineering, Faculty of Engineering, Uludag University, Bursa, Turkey
[2]Department of Mechanical Engineering, Faculty of Engineering, Bursa Orhangazi University, Bursa, Turkey
[3]Magneti Marelli MAKO Elektrik Sanayi Ticaret A.Ş. Bursa Turkey

*Corresponding author:
Email: myazici@uludag.edu.tr

Received: April 30, 2015
Accepted: June 11, 2015

Abstract

New regulations about pedestrian safety entail the automobile producers to improve headlamp designs by reducing the pedestrian injury during the event of car headlamp-pedestrian crash. In this study, a lightweight commercial vehicle headlamp was modeled with finite element method and simulated under pedestrian impact. This work aims to predict the behavior of headlamp during the pedestrian crashes. Initially, Finite Element Analysis of a sample headlamp model and regular pedestrian impactors were prepared. Then, static, modal and Dynamic/Explicit analyzes were executed, respectively. The results show that the current model of headlamp was matched with the new pedestrian protections regulations of EEVC/WG17.

Keywords: Pedestrian Safety, Finite Element Analysis, Crashworthiness, Head Lamp.

INTRODUCTION

Recently, pedestrian safety has become an important issue for vehicle design and production. Vehicle manufacturers perform research and development studies for vehicle's crashworthiness in the event of a frontal collision. In Turkey, 24% of urban traffic accidents fatalities are caused by pedestrian-vehicle collision [1]. In Europe, 21% of urban traffic accidents fatalities is caused by same reason [2]. The design of frontal side of vehicles has become more pedestrian-friendly since 1980's. The frontal structure of vehicles has smooth lines for pedestrian safety. Working Group 17 of the European Enhanced Vehicle Safety Committee (EEVC/WG17) developed three test methods for determining the behavior of pedestrian-vehicle collision which are the legform to bumper test, the upper legform to bonnet leading edge test and the headform to bonnet top test [3]. Four impactor models is proposed for performing the subsystem tests. These impactors present human body parts. The lower legform and the upper legform present tibia, femur and pelvis, adult and child headforms presents head. Impactors utilize instead of full-scale dummy models. Using impactors for tests provides reducing test costs. Also significantly reduce the simulations time.

Teng and Nguyen modeled the impactors for crash analysis [4]. Materials properties at high strain rate which use in child headform were investigated [5]. In this study, in specifically focus on the headlamp of connection region during pedestrian-vehicle collision.

Therein, connection region of headlamp was examined for pedestrian safety. Figure 1 represents impactors and crash regulation between the pedestrian-vehicle collisions proposed by EEVC/WG17. Child headform and headlamp were modeled for static, modal and non-linear dynamic/explicit finite element analyzes.

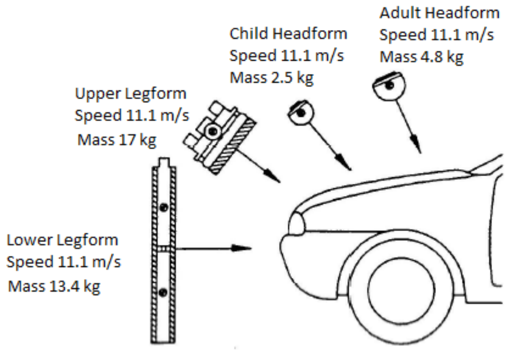

Figure 1. Pedestrian protection test methods [3]

MATERIALS AND METHODS

In this study, three different analysis; static, modal and the non-linear dynamic impact was conducted. Two different finite element model was executed for these analyzes. The software used in the simulations was Abaqus/Standard and Abaqus/Explicit. Material constants of low and high strain rate were determined using the universal tensile machine and split Hopkinson pressure bar equipment for non-linear dynamic analysis respectively.

Static and Modal Analysis

Figure 2 shows the components of the headlamp. Table 1 presents the material constants for finite element analysis. Finite element model was prepared in Abaqus software. All components were modeled as elastic materials. Linear contacts were used for static and modal analysis. All components were composed of solid elements. The headlamp model consists 627 047 nodes, 2 328 007 linear tetrahedral elements, and 2924 linear hexahedral elements.

Total mass is 2.94 kg for the headlamp model. Figure 3 presents the finite element model of the headlamp. Static analysis was conducted under the gravity boundary condition. Also, same finite element model is used for modal analysis. First four mode shapes is obtained from the modal analysis. Same boundary conditions are used for modal analysis.

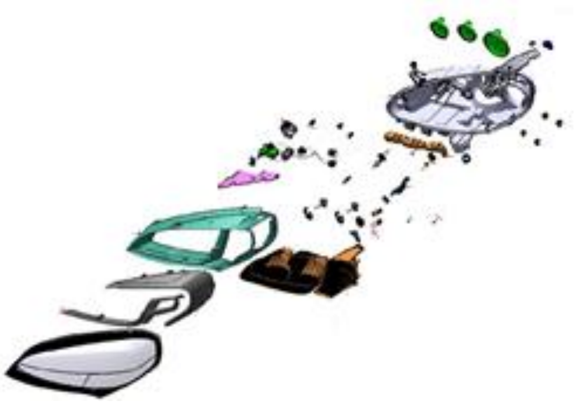

Figure 2. Components of the headlamp

Table 1. Mechanical properties of components of headlamp

Materials	Young Modulus (MPa)	Density (g/cm^3)	Poisson Ratio	Yield Strength (MPa)
PC	2350	1.2	0.38	63
PBT	2400	1.3	0.28	60
PPTD40	3500	1.2	0.38	32
BMC	13000	1.9	0.35	77
POM	3000	1.42	0.35	72

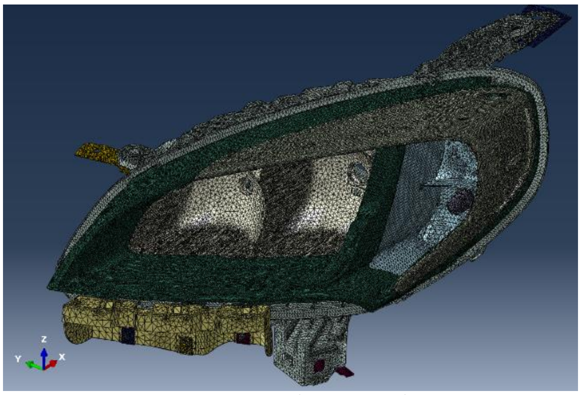

Figure 3. Finite element model of headlamp for static and modal analysis

Dynamic Analysis

Experimental Setup

PPTD40 specimens were tested using a uniaxial tensile machine for quasi-static loading and split Hopkinson pressure bar for dynamic analysis. Stress-Strain Curves were obtained from experiments. Figure 4 shows the specimens for the low strain (10-2 1/s) tests. The specimens were produced by using plastic injection mold. Figure 5 represents plastic injection mold. PPTD40 specimens for high strain rates (1460, 2455, 2858 1/s) were cylindrical and specimens dimensions are 9.5x4.5mm (diameter x length). Figure 6 shows stress-strain curves obtained from Split-Hopkinson Pressure Bar (SHPB) test results. Figure 7 represents stress-strain curve at low strain rate.

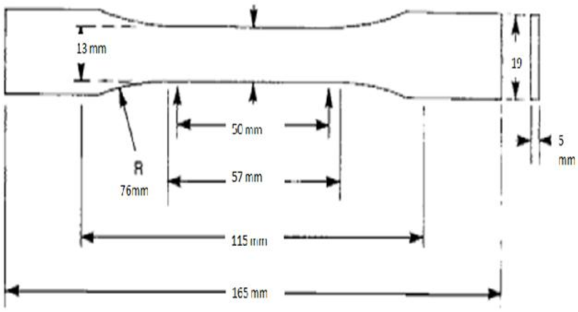

Figure 4. Specimen of PPTD40 (ASTM D638)

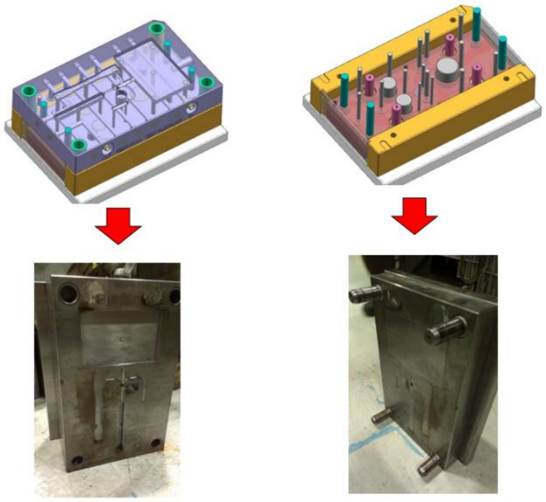

Figure 5. Plastic injection mold of specimens

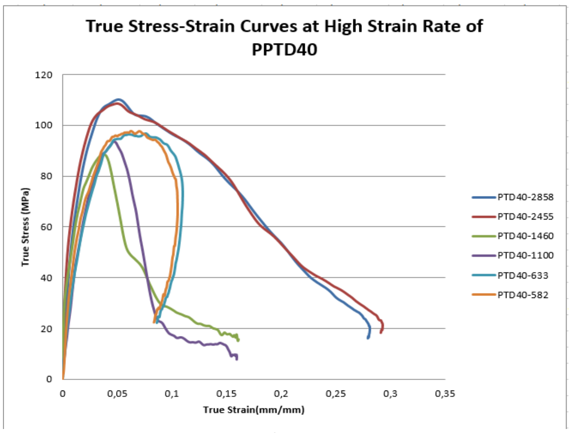

Figure 6. Stress-Strain curves of PPTD40 with high strain rates .

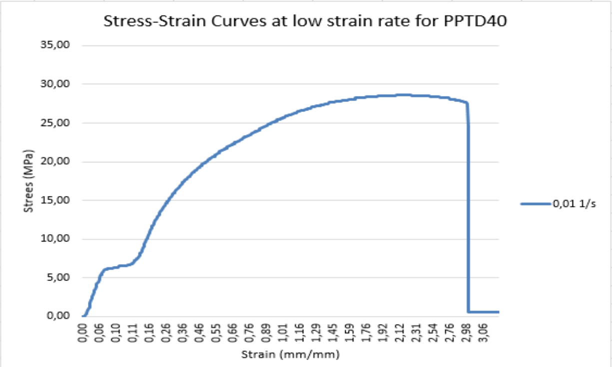

Figure 7. Stress-Strain Curve of PPTD40 with low strain rate.

Material constants at low and high strain rate of PC were determined by Army Research Laboratory. Compression at low and high rate tests were conducted by using the tensile machine and SHPB. Material constants were calculated for the Johnson-Cook material model [6].

$$\sigma_f = (A + B\varepsilon_p^n)\left[1 + C\ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)\right]\left[1 - \left(\frac{T - T_0}{T_f - T_0}\right)^m\right] \; with\, T \geq T_0 \quad (1)$$

Herein, A, B, C, n, m: coefficient of the model, $\dot{\varepsilon}_0$: reference strain rate, T: temperature, T_0: reference temperature, T_f: melting temperature.

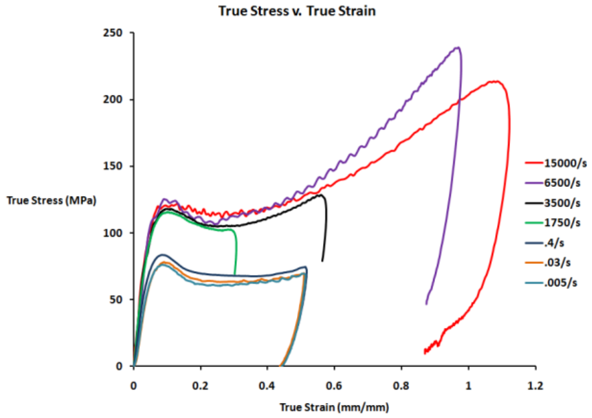

Figure 8. Stress-Strain curves of PC with low and high strain rates [6]

Table 2. Johnson-Cook parameters for PC [6]

A=	80 MPa
B=	75 MPa
C=	0.052001 ----
m=	0.548 ----
n=	2----
T_{melt}	562 K
β=	0.5----
ρ=	1220 kg/m^3
$C_{V=}$	1.3 KJ/(kg K)

Numerical Setup

In this section, child headform and headlamp finite element model were prepared. Figure 9 shows child headform. Child headform impactor is a sphere made of aluminum covered with an 11±0.5mm vinyl skin. The Vinyl skin modeled with viscoelastic material and aluminum core as an elastic-plastic material. The child headform finite element model consists of 23,946 nodes and 110,589 linear tetrahedral elements.

Housing is made of Polypropylene reinforced Talc (PPTD40). Housing is modeled as an elastic-plastic material that constants are taken from the experiment. Lens is made of Polycarbonate (PC) material. It is also modeled as an elastic-plastic material model, the plastic behavior depends on a Johnson-cook constative material model. Figure 10 illustrates the finite element model of non-linear dynamic analysis.

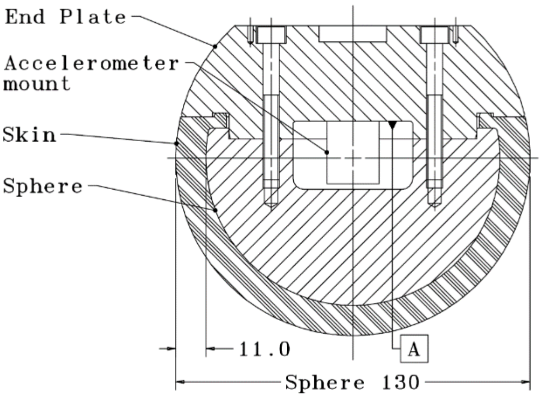

Figure 9. Child headform impactor (dimensions in mm) [3]

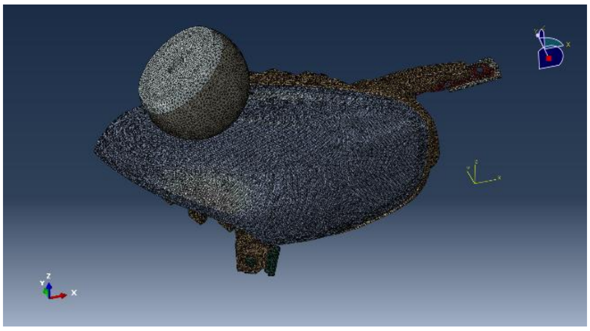

Figure 10. Finite element model of non-linear dynamic analysis.

Entire finite element model consists 531,747 nodes and 1,851,841 linear tetrahedral elements. Child headform was impacted with the speed of 11.1 m/s according to EEVC regulations to the headlamp upper top surface with a 55 angle from ground plane [3]. In the dynamic analysis, the model simplified due to reducing solution time, and only the lens and housing of headlamp were selected.

RESULTS AND DISCUSSION

In this study, static, modal, and non-linear dynamic crash analyzes were executed. Elastic material constants were used in static and modal analyzes. Under the boundary condition of gravity loading, the Finite Element Model of static analysis results were examined for evaluating the connected surfaces of the headlamp. Figure 11, 12 and 13 illustrates the results of static analysis under the gravity load. According to results, the connections between the housing and chassis are in the safety zone. (Yield Stress of PPTD40 is 32 MPa). Figure 14 and 15 represent the results of modal analysis calculated for the first four mode shapes. The car OEM company that use this headlamp expected for the headlamp the first natural frequency must be greater than 42 Hz. In this modal analysis, the results were satisfied with this criterion.

The results of collision analysis between the headlamp and child headform non-linear Dynamic/Explicit analysis can be seen in figure 16. As in figure 16 most critical parts are in the connection regions.

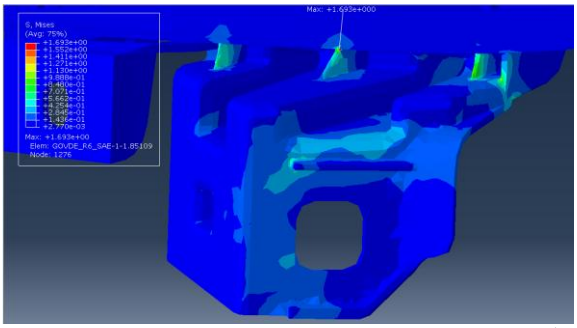

Figure 11. Von-Misses distribution under gravity load for connection 1 (Max Stress 1.69 MPa)

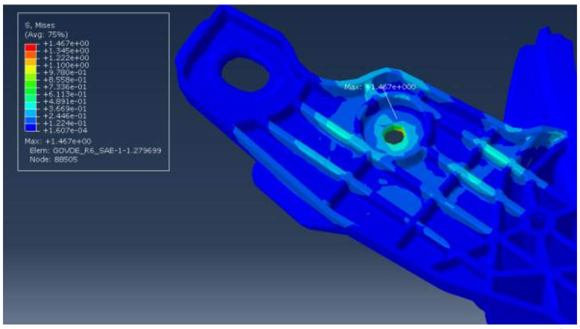

Figure 12. Von-Misses distribution under gravity load for connection 2 (Max Stress 1.467 MPa)

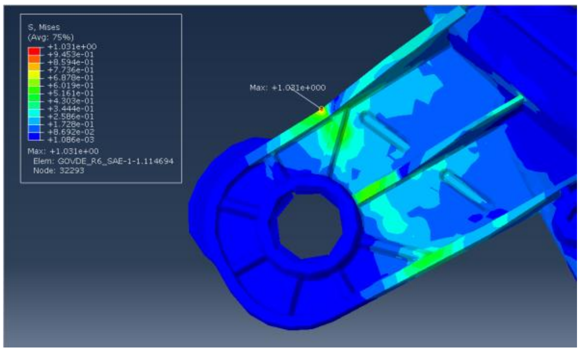

Figure 13. Von-Misses distribution under gravity load for connection 3 (Max Stress 1.031 MPa)

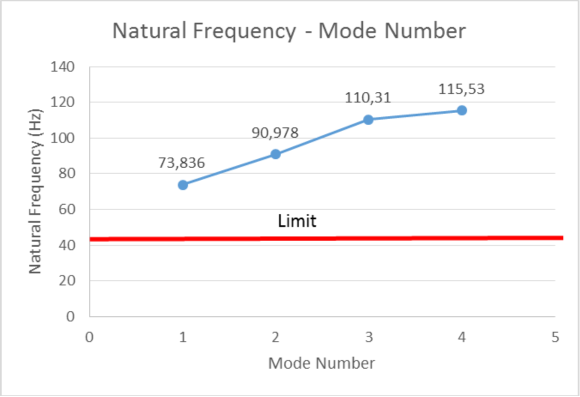

Figure 14. First four mode

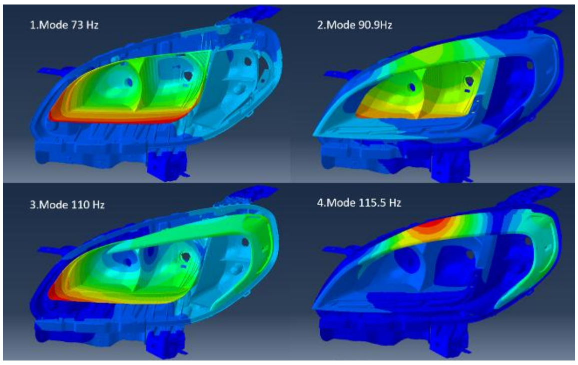

Figure 15. First four mode shapes of headlamp

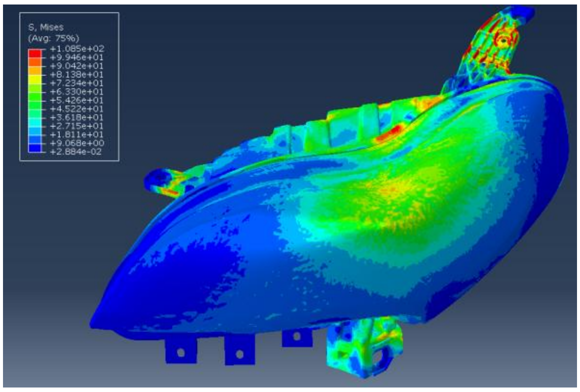

Figure 16. Headlamp after the collision.

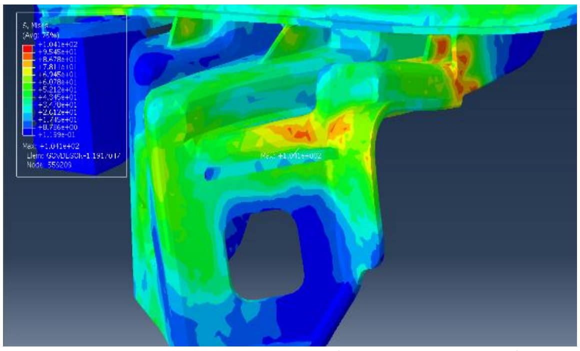

Figure 17. Von-Misses distribution of the connection I after the impact event (Max Stress 104.1 MPa)

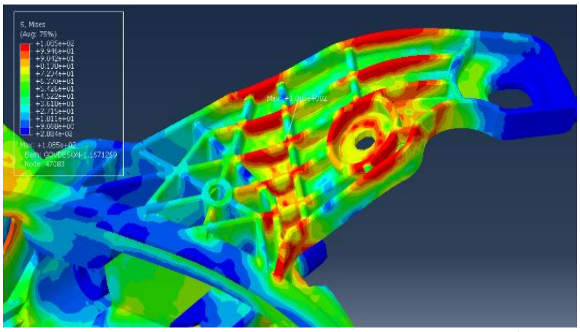

Figure 18. Von-Misses distribution of the connection II after the impact event (Max Stress 108.5 MPa)

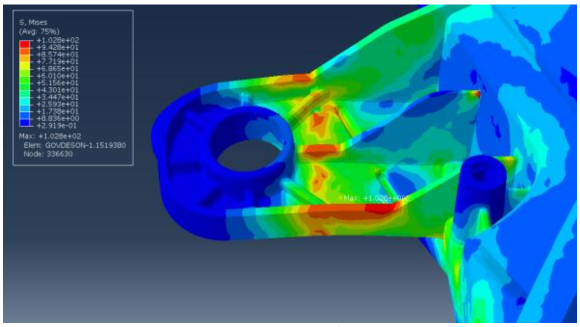

Figure 19. Von-Misses distribution of the connection II after the impact event (Max Stress 102.8 MPa)

CONCLUSIONS

In this study, a series of numerical simulations were performed for quasi-static, modal and dynamic loading conditions. The new regulations directed to designers through the lens of the headlamp should be uniform during impact events. However, the housing connection regions should be broken before all of the front parts of the headlamp. This purpose can be obtained by selecting proper materials and shaping the headlamp parts.

The headlamp model all natural frequencies are over the limit values.

The criteria of the lens design, it has to resist under quasi-static, and dynamic loading conditions without any damage occur.

FEM simulations showed that the lens is an expected strength under quasi-static loading conditions.

The housing material and lens materials are very high strain rate sensitive materials. That means the strength of the housing and lens increased under dynamic loading conditions. For that reason, the obtained maximum Von Mises equivalent stress in the pedestrian impact simulation was lower than the dynamic strength of the lens material's maximum strength. However, in the housing maximum Von Mises equivalent stresses were obtained higher than the critical limit of the dynamic materials stress. This result is matched with the design criteria and new pedestrian protection regulations needs.

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