International Journal of Natural and Engineering Sciences 9 (2): 01-06, 2015
ISSN: 1307-1149, E-ISSN: 2146-0086, www.nobel.gen.tr

# The Influence of Different Design Parameters by means of Analysis and Optimization in a Car Chassis

Abdulkadir YAŞAR[1]* Durmuş Ali BIRCAN[2]
[1]Department of Mechanical Engineering, Faculty of Ceyhan Engineering, University of Cukurova, Ceyhan, Turkey
[2]Department of Mechanical Engineering, Faculty of Engineering and Architecture, University of Cukurova, Adana, Turkey

*Corresponding author:
Email: ayasar@cu.edu.tr

Received: March 13, 2015
Accepted: April 22, 2015

**Abstract**

The main challenge in today's vehicle industry is to implement the increasing demands for higher performance, longer life, and lower weight of components so as to satisfy fuel economy demands, at a realistic cost using new safety requirements. In this work, optimum design parameters of the car chassis were examined by taking into account different chassis types, dimensions, and different materials in order to achieve minimum weight and deflection. Initially, three chassis types with three sections (Rectangular, L type and Circular) were designed with the help of Computer Aided Designed (CAD) method via SolidWorks™ software. After that, each design was analyzed using Finite Element Analyses (FEA) method applying aluminum alloy, magnesium alloy and carbon fiber materials. Forces were applied according to weights that will be attached to obtain the more realistic results. The consequences of the analysis were optimized by Taguchi method with Minitab.

**Keyword: Vehicle Chassis, Computer Aided Design, FEA, Taguchi method.**

## INTRODUCTION

The main pressures on vehicle designers and engineers continue to be safety and exhaust emissions, together with fuel economy. However, intense competition, especially towards the top of the market, means that comfort and sheer ease of driving are also important considerations. They can make the difference between winning and losing the customer. Consequently, a great deal of engineering effort has lately been devoted to the chassis - in its modern sense of suspension, brakes and steering [1-7]. Considerations of the chassis types that want to design must be made in order to manufacture the most energy efficient car. Basically, the types of chassis design consist of backbone, space frames, monocoque, ladder frame, and semi backbone. Each of chassis designs has their own strengths and weaknesses. Every chassis types are considered between weight, component size, complexity, vehicle intent, and ultimate cost. Even within a basic design method, strength and stiffness can vary significantly depending on the designing. An ideal chassis is the one that has high stiffness with low weight and cost.

The chassis has to contain the various components required for the vehicle chassis as well as being based around a driver's cockpit. The safety of the chassis is a major aspect in the design, and should be considered through all stages. The design also has to meet strict requirements and regulations. Many people think that the chassis which was built from aluminum is the path to the lightest design, but this is not necessarily true. Aluminum is more flexible than steel. In fact, the ratio of stiffness to weight is almost identical to steel, so an aluminum chassis must weigh the same as a steel one to achieve the same stiffness. Aluminum has an advantage only when there are in very thin sheet sections where buckling is possible but that are not generally the case with tubing. The uses of aluminum and FRP in designing the chassis are contribute to reduce overall vehicle weight, thereby decreasing fuel consumption as well [8-10].

### Basic Concept of FEA

Finite Element Analysis has now become an integral part of Computer Aided Engineering (CAE) and is being extensively used in the analysis of many tedious real time problems. The field of finite element analysis is matured and depends on rigorous mathematical foundation. Many powerful software tools and packages are available, promoting its widespread use in industries [11, 12]. The Finite Element Method (FEM) is a computational technique used to achieve approximate solutions of boundary value problems in engineering. If simply expressed, a boundary value problem is a mathematical problem in which one or more dependent variables must satisfy a differential equation everywhere within a known domain of independent variables and satisfy specific conditions on the boundary of the domain. An unsophisticated description of the FE method is that it involves cutting a structure into several elements pieces simple way, then reconnecting elements at nodes as if nodes were pins or drops of glue that hold elements together.

There are three main steps, namely: preprocessing, solution and post processing. In pre-processing (model definition) includes: define the geometric domain of the problem, the element type(s) to be used, the material properties of the elements, the geometric properties of the elements (length, area, and the like), the element connectivity (mesh the model), the physical constraints (boundary conditions) and the loadings. In solution includes: the governing algebraic equations in matrix form and computes the unknown values of the primary field variable(s) are assembled. The computed results are then used by back substitution to determine additional, derived variables, such as reaction forces, element stresses and heat flow. In post processing, the analysis and evaluation of the result is conducted in this step as shown in Figure 1.

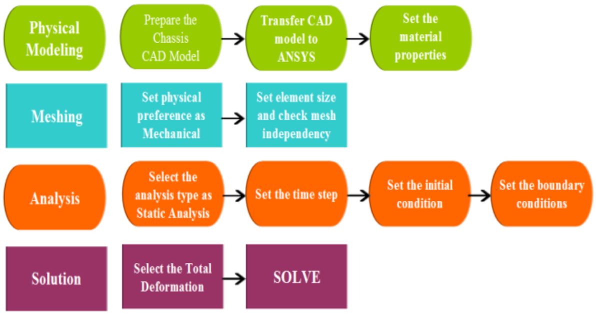



**Figure 1.** Proposed procedure for FEA using ANSYS

### Taguchi method

The Taguchi robust parameter design has been widely used over the past decade to solve many single response process parameter designs. The Taguchi method, utilizing orthogonal arrays (OAs) to design an experiment and signal-to-noise ratio (SNR) to evaluate response performance of experimental runs, has been used in many single response applications to determine the optimal parameters/levels combination to reduce response variation and simultaneously bring the mean to the desired value [13].

The Taguchi method involves reducing the variation in a process through robust design of experiments. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning [14]. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors are most effective in product quality with a minimum amount of experimentation, thus saving time and resources [15].
The general steps involved in the Taguchi method are as follows:

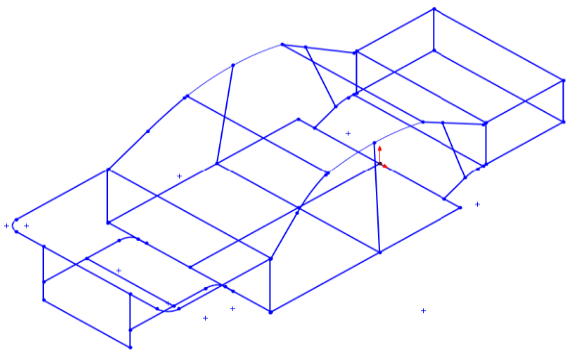
1. Define the process objective, or more specifically, a target value for a performance measure of the process.
2. Determine the design parameters affecting the process. Parameters are variables within the process that affect the performance measure such as.
3. Create orthogonal arrays for the parameter design indicating the number and conditions for each experiment. The selection of orthogonal arrays is based on the number of parameters and the levels of variation for each parameter.
4. Conduct the experiments indicated in the completed array to collect data on the effect of the performance measure.
5. Complete data analysis to determine the effect of the different parameters on the performance measure.

In this study, optimum design parameters of the car chassis were investigated by considering different chassis types, dimensions, and different materials in order to obtain minimum weight and deflection. Firstly, three chassis types with three sections, such as rectangular, L type and circular, were designed using SolidWorks$^{TM}$ software. Then, each design was analyzed using Finite Element Analyses (FEA) applying various materials utilized in automotive sector as, aluminum alloy, magnesium alloy and carbon fiber. Forces were applied according to weights equipped with the chassis to obtain the more realistic results. The results of the analysis were optimized using Taguchi method with Minitab. At the last step, 3 different optimum designs were determined and compared with each other.

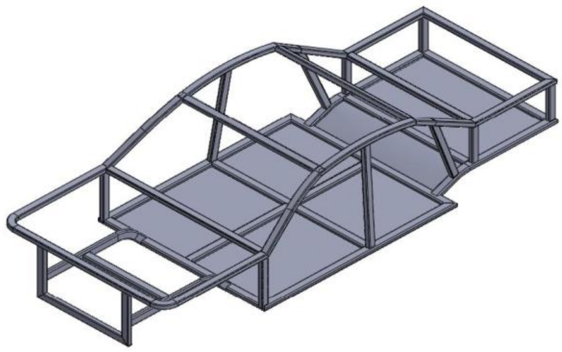
## MATERIAL AND METHODS

### Design Steps

In this stage; 3D sketch of the vehicle is firstly drawn using Solidworks as shown in Figure 2 (a). Then, the profiles are attached to the chassis by welding. The parts inside the weldments are trimmed. The 2 mm sheet metals profiles are connected to chassis given in Figure 2 (b).



(a)



(b)

**Figure 2.** (a) 3D sketch of the vehicle (b) Profiles attached to the chassis

Chassis must be rigid and strong enough to absorb the vibrations caused by engine, suspension, and drive line. The most commonly used materials for chassis are aluminum alloy which is called 201.0-T6 Insulated Mold Casting (SS) [11], magnesium alloy [12] and carbon fiber which is called thermoset composite [16-18]. Their densities are quite low in comparison with steel and iron. Material properties can be seen in Table 1.

**Table 1.** Material properties

| ***Material Types*** / ***Material Properties*** | ***Aluminum Alloy*** | ***Magnesium Alloy*** | ***Carbon Fiber*** |
|---|---|---|---|
| Density | 2800 kg/m$^3$ | 1740 kg/m$^3$ | 1570 kg/m$^3$ |
| Ultimate Tensile Strength | 359 MPa | 255 MPa | 810 MPa |
| Yield Strength | 349 MPa | 193 MPa | 200 MPa |
| Poisson's Ratio | 0.33 | 0.35 | 0.3 |
| Young's Modulus | 71 GPa | 45 GPa | 190 GPa |

**Cross Sections**

In this stage, three different cross section types such as rectangular, L type and circular, as shown in Figure 3, with three dimensions, provided in Table 2, are used for the structure of design.

**Table 2.** Cross section dimensions

| Cross Section Type | Levels | Cross Section Dimensions |
|---|---|---|
| Rectangular Type Cross Section | 1 | 50 mm x 30 mm<br>60 mm x 40 mm<br>70 mm x 40 mm |
| L Type Cross Section | 2 | 20 mm x 20 mm<br>25 mm x 25 mm<br>35 mm x 35 mm |
| Circle Type Cross Section | 3 | 21.3 mm x 2.3 mm<br>26.9 mm x 3.2 mm<br>33.7 mm x 4.0 mm |

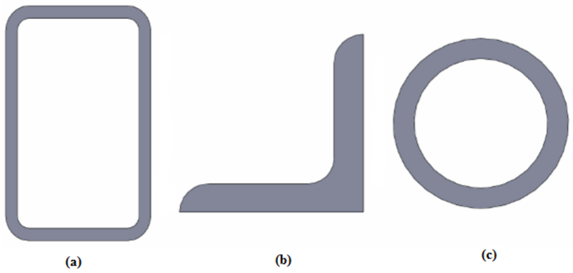



**Figure 3.** Cross section types

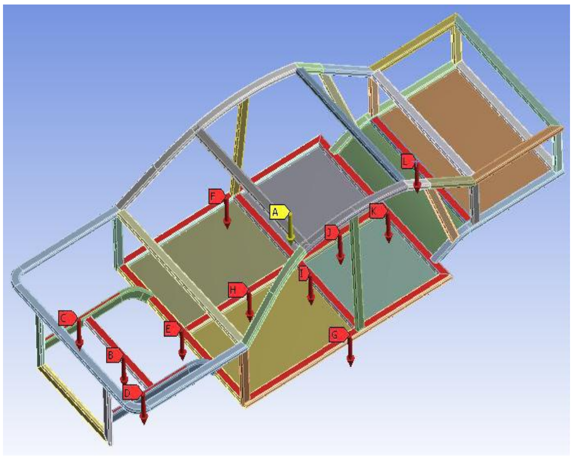


**Figure 4.** Force Distribution of Total 4600 N on chassis

**Forces**

Different distributed forces were applied to the whole chassis body in order to obtain Von Mises Stresses. At the front of the chassis, constant forces were applied throughout all analysis. The engine and its component were assumed to be approximately 204 kg corresponding 2000 N.

For total 4600 N force distribution; at the middle of the chassis, 2000 N force was applied considering two people sitting in front of the cabin. Also, 55 kg seats' weights were taken into consideration. For the rear of the chassis, force of 600 N was applied consisting of the gasoline tank with 7 kg and 61 liter gasoline with full tank of 54 kg when the density of gasoline was taken as 0.879 g/cm$^3$. Total 4600 N force distribution is listed in Table 3 and seen on chassis in Figure 4.

**Taguchi-based experimental design**

The Taguchi parameter design phase serves towards the objective of determining the optimal chassis parameters in order to achieve the lowest Von Mises Stresses and weight.

The relationship between the control factors (material, cross section, and cross section dimensions) and output response factors (Stresses) and the optimal conditions of the parameters considered in this study.

**Table 3.** Force distribution of total 4600 N

| Forces Types | Standard Earth Gravity=A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Forces Values (N) | 9.81 m/s2 | 1000 | 500 | 500 | 100 | 250 | 250 | 500 | 500 | 250 | 150 | 200 |

**Table 4.** Parameters and levels used for orthogonal array

| **Control Factors** | **Level 1** | **Level 2** | **Level 3** |
|---|---|---|---|
| Materials | Aluminum Alloy | Magnesium Alloy | Carbon Fiber |
| Cross section | Rectangular | L type | Circular |
| Cross section dimensions | 1 | 2 | 3 |

**Table 5.** All test results during FEA in Taguchi-based experimental design

| Material | Cross Section | Cross Section Dimension | Max.Total Deformation for Total 4600 N (mm) | Max.Von Misses Stress for Total 4600 N (MPa) | SNRA1 | MEAN1 | Weights (kg) |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 2.8228 | 94.585 | 39.56534 | 95.1235 | 85.61 |
| 1 | 1 | 2 | 1.9052 | 21.94 | 26.95117 | 22.269 | 98.04 |
| 1 | 1 | 3 | 1.937 | 27.302 | 28.94625 | 28.039 | 120.6 |
| 2 | 1 | 1 | 3.184 | 77.466 | 37.86326 | 78.2025 | 53.2 |
| 2 | 1 | 2 | 2.1241 | 18.893 | 25.67151 | 19.2205 | 60.92 |
| 2 | 1 | 3 | 2.1218 | 22.881 | 27.44413 | 23.594 | 74.94 |
| 3 | 1 | 1 | 0.69882 | 74.12 | 37.469995 | 74.7385 | 48 |
| 3 | 1 | 2 | 0.47083 | 18.867 | 25.66211 | 19.2 | 54.97 |
| 3 | 1 | 3 | 0.46846 | 22.784 | 27.41733 | 23.524 | 67.62 |
| 1 | 2 | 1 | 7.6911 | 105.7 | 40.56491 | 106.735 | 69.5 |
| 1 | 2 | 2 | 1.8476 | 57.524 | 36.56625 | 71.208 | 74.09 |
| 1 | 2 | 3 | 3.8973 | 31.602 | 30.25917 | 32.629 | 82.75 |
| 2 | 2 | 1 | 8.2442 | 75.6 | 38.17746 | 81.768 | 43.19 |
| 2 | 2 | 2 | 2.6435 | 49.943 | 35.45522 | 63.478 | 46.04 |
| 2 | 2 | 3 | 4.5314 | 26.67 | 29.17537 | 29.05 | 51.43 |
| 3 | 2 | 1 | 1.818 | 84.782 | 38.7495 | 86.652 | 38.97 |
| 3 | 2 | 2 | 0.61813 | 50.051 | 35.49052 | 63.8655 | 41.54 |
| 3 | 2 | 3 | 1.0146 | 27.595 | 29.47798 | 30.0865 | 46.4 |
| 1 | 3 | 1 | 1.8429 | 29.728 | 30.08439 | 32.2195 | 71.04 |
| 1 | 3 | 2 | 1.7413 | 26.719 | 29.147597 | 28.9165 | 77.39 |
| 1 | 3 | 3 | 1.6063 | 24.036 | 27.99076 | 25.1685 | 85.84 |
| 2 | 3 | 1 | 2.6433 | 27.575 | 29.4599 | 30.012 | 44.14 |
| 2 | 3 | 2 | 2.4909 | 24.642 | 28.500899 | 26.891 | 48.09 |
| 2 | 3 | 3 | 2.279 | 22.691 | 27.56667 | 24.004 | 53.35 |
| 3 | 3 | 1 | 0.6185 | 28.634 | 29.79562 | 31.2035 | 39.83 |
| 3 | 3 | 2 | 0.5825 | 25.583 | 28.82404 | 27.908 | 43.39 |
| 3 | 3 | 3 | 0.53375 | 22.636 | 27.54672 | 23.9495 | 48.13 |

A standardized Taguchi-based experimental design L27 (33) was chosen to accommodate three control factors into the experimental study, as shown in Table 4. There were 27 experimental runs that need to be conducted with the combination of varying levels of each control factor. The selected parameters were also displayed in Table 5 with their codes and values.

## RESULTS AND DISCUSSION

**Results of Finite Element Analysis**

CAD model of chassis is created and imported in to FEA software ANSYS for finite element analysis. For the analysis, a distributed load of 4600 N applied on the chassis by considering passenger capacity, the weight of the vehicle components, and batteries. The analyses have been conducted with three different materials. The aim of the design was to obtain a minimum deflection value. Considering control factors including material, cross section, cross section dimensions and output responses as maximum stresses and the optimal conditions of the parameters, 27 different design alternatives were obtained. Three optimum design solutions have been obtained by means of boundary conditions, maximum total deformation and von-Misses stress, as illustrated in Figure 5 to Figure 7 and Table 6.

## CONCLUSION

In this present study, design and analysis of the vehicle chassis have been conducted so as to determine optimal design parameters. The chassis was designed via SolidWorks and the analyses were executed by means of ANSYS. The main objective of chassis design is to withstand the loads with a specific strength and stiffness while taking into account weight, cost and easy fabrication. Following conclusions can be summarized;

Analyses have been performed by varying the material, cross section and cross section dimensions for the chassis. Aluminum alloy, magnesium alloy and carbon fiber materials have been used in combination with three different cross section types like rectangular, L and Circular.

Three alternative designs were achieved in terms of total deformation and weight. One of them is carbon fiber, rectangular and 60 mm x 40 mm. Another one is magnesium alloy, L type and 35 mm x35 mm. The other is magnesium alloy, Circle, 33.7 mm x 4.0 mm.

Of these alternative designs, sequence of 312 gives the best solution in view of maximum deformation which has 0.47083 mm, and sequence of 223 submits the best solution in terms of weights which is 51.43 kg.

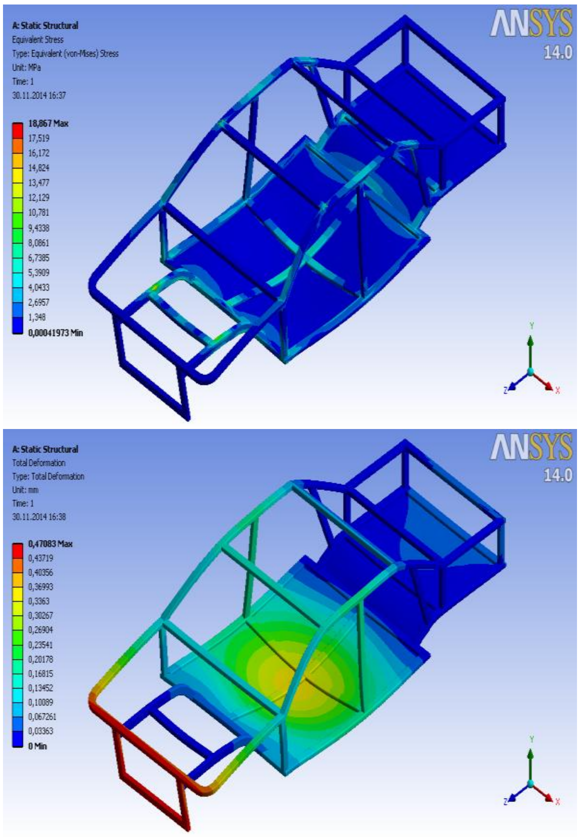
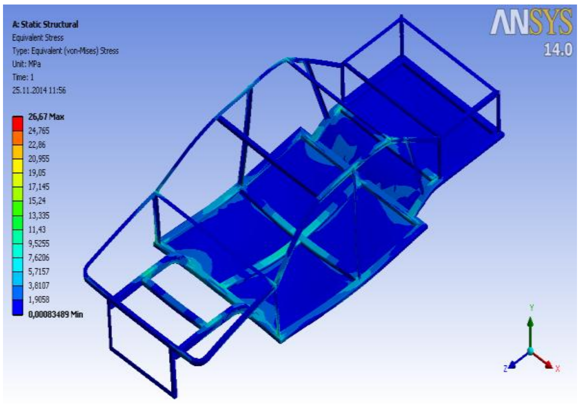



**Figure 5.** Maximum deformation and equivalent stress in vehicle chassis for first alternative



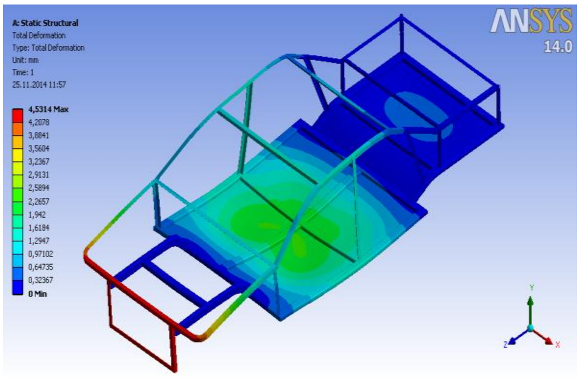




**Figure 6.** Maximum deformation and equivalent stress in vehicle chassis for second alternative

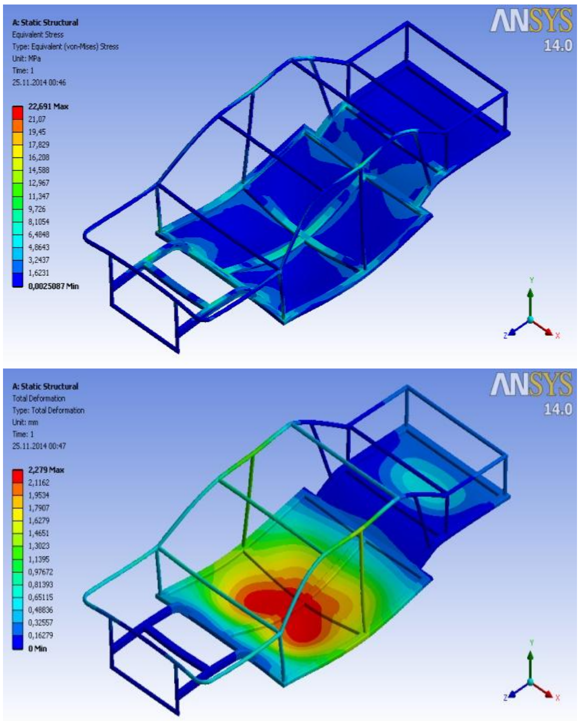



**Figure 7.** Maximum deformation and equivalent stress in vehicle chassis for last alternative design

**Acknowledgements**

This study has been supported by Çukurova University Scientific Research Projects Unit with the project number of 4890.

**Table 1.** Alternative optimum design solutions

| Material | Cross Section | Cross Section Dimension | Max.Total Deformation (mm) | Max. Von Misses Stress (MPa) | SNRA1 | MEAN1 | Weights (kg) |
|---|---|---|---|---|---|---|---|
| 3 | 1 | 2 | 0.47083 | 18.867 | 25.66211 | 19.2 | 54.97 |
| 2 | 2 | 3 | 4.5314 | 26.67 | 29.17537 | 29.05 | 51.43 |
| 2 | 3 | 3 | 2.279 | 22.691 | 27.56667 | 24.004 | 53.35 |

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