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# Reduced Weight Automotive Brake Pedal Test & Analysis

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**Abstract**

Currently, automotive industry continues to strive for light weight vehicle for improving fuel efficiency and emission reduction. It is crucial to design vehicles with an optimum weight for a better performance of the car. In this field, which has boundaries with fixed standards and regulations, manufacturers continue to work on characteristics, structures and types of the material to develop new components, which have same safety specifications but cheaper and lighter than current products.

In this study, the strength analysis of a new design of an automotive brake pedal is presented. In order to reduce the weight, an alternative design, plasma welded two parts is studied instead of a monoblock gas arc welded brake pedal arm. The estimation of the design life of both current and the new pedal, a linear static stress analysis was performed via finite element method. Here, critical regions where the stress concentration occurs were determined. Stress-life method was used to estimate the fatigue life of the brake pedal. Based on the analysis results, design enhancement solutions were applied to extend the life of the new brake pedal. The computational analysis of the fatigue life of the pedal is validated utilizing a custom made test setup.

*Keywords*: Brake pedal; Fatigue life; Finite element analysis; Strength analysis

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## 1. Introduction

Automotive industry continues to strive for light weight vehicle for improving fuel efficiency and emission reduction. It is crucial to design vehicles with an optimum weight for a better performance of the car. If the vehicle mass reduced, the needed energy to move the vehicle is decreased. In general, for every 10% reduction in vehicle weight, the fuel consumption of vehicles is reduced by 5-7% [13,14]

A typical automobile brake system operates by transmitting the force applied by the driver on the brake pedal, via hydraulic brake fluid, to brake at each wheel. Since, the brake fluid is incompressible and it can transmit all the force applied at the brake pedal to the brakes [1,11]. The brake pedal in motor vehicles has the task of providing the driver's command through foot leg on master cylinder of the brake system in a vehicle during stopping or reducing speed of a vehicle. The pressure is required by the brakes which reduce speed and stop automobile is much greater than the pressure that drivers could physically apply with their foot; in general 3 cascaded force multiplication mechanisms aid to increase the braking pressure. First, the brake pedal is specially designed as a lever to multiply the force applied by the driver. Second, a vacuum booster unit is utilized to assist braking by increasing the pressure of the hydraulic circuit. Third, the relative surface areas of the master cylinder pistons, which actually the brake fluid push on and determines the hydraulic multiplication factor. As a result, a driver's foot force of several tens of Newtons becomes several thousands of Newtons at the brakes [1,11]. In braking conditions, a heavy person can easily push with a force greater than 300 N. If the force is quickly applied on the pedal, the effect of sudden force further increases the stress on the pedal [2]. The basic scheme of the brake pedal assembly is depicted in Fig. 1.

The conventional brake pedals for the automobile industry are made by press forming of steel strips previously formed to adequate shapes and dimensions. It is known that the manufacturing of steel brake pedals with press forming method may cause cracking problems. The cracks were detected in critical zones of the part revealing a possible lack of ductility in the constitutive material [3]. In literature, there a number of published works on steel or other alternative material pedal designs. Typical properties of composite are available in manufacturer's literature, handbooks and other resources. In the literature, there is a lot of work including design, experiment which is necessary to introduce brake pedal from metal to polymer composites [4,5,6,9,10,11,12].

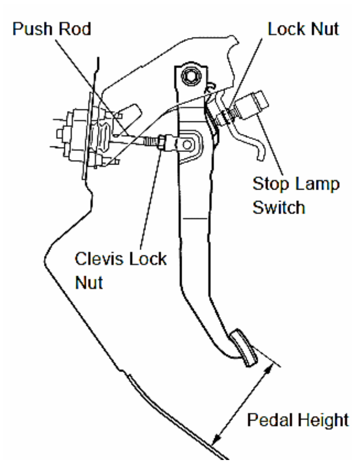


Fig. 1. The basic scheme of the brake pedal assembly (2004 Prius – Preliminary Release)

Still, in current applications, solid sheet materials, whose thickness is 8 mm, are used to produce brake pedal, as seen Fig. 2. In the new design that we introduce, the pedal (Fig.3) requires two welded materials; each of them has 1.4mm thickness. In current technique, gas metal arc welding system is used for 8mm thickness material. When this same welding system is used for 1.4mm thickness material, some problems arise such as holes in welding area, inadequacy in dilution. Due to the facts, it is decided that plasma welding system, which is most suitable for thin materials, is employed. Although different types of plasma technics are tried in different areas of manufacturing, and it is the first time to use plasma welding method for the pedal production.

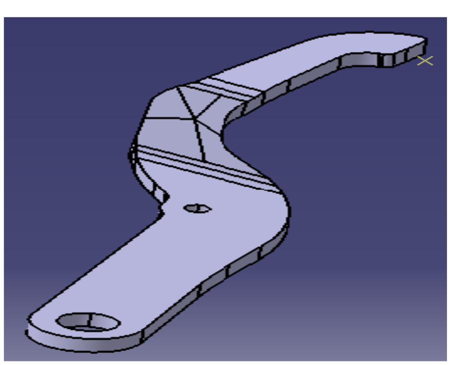

Fig. 2. Cad Model of 8 mm monoblock pedal

The successful production of the brake pedals with 1.4mm thickness material decreases weight of the pedal in the car about %33. In the following section, both monoblock pedal and different plasma welded brake pedal designs are analyzed using finite element analysis method and compared. First linear static stress analysis is used then fatigue analysis is completed to estimate the design life of the brake pedal designs.

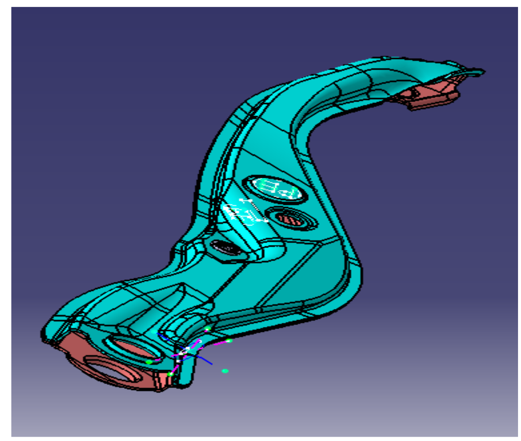

Fig. 3. Cad model of two pieces plasma welded pedal

## 2. Stress Analysis

### *2.1 Finite Element Model*

A brake pedal consists of three parts: pedal arm, support and seat. In the new design, two parts of pedal arm and seat are joined using plasma welding. In order to predict the stress magnitude at the damage regions of the brake pedal, a full scale solid model of the pedal was built using Catia© R22 commercial software. In order to build the finite element model, shown in Fig. 4, the cad model is imported into Ansys Workbench© v15.0 pre-processing environment. The finite element model consists of approximately 196.000 elements and 335.200 nodes. As the contact condition for all welded surfaces, bonded contact is chosen.

### *2.2 Load Model*

Analyzed pedal is manufactured from SPC 440 sheet material. Material properties are given in Table1. According to the standards and work in the literature, a 500 N force is used to predict the fatigue life test of brake pedals [7]. In order to simulate the real pedal force in the analysis a 500 N load is applied on surface of the seat part of the pedal. Pedal is fixed on the support holes. In order to present the effect of the master cylinder hydraulic on the pedal, a piston and cylinder are also added to the analysis. (Fig. 5)

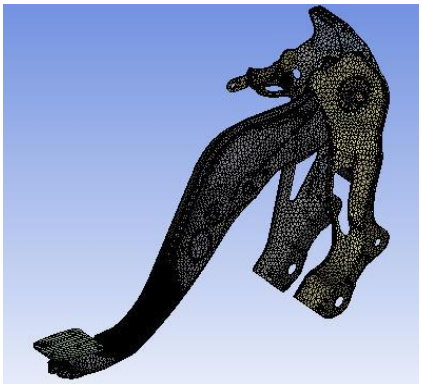

Fig. 4. Finite element model of brake pedal

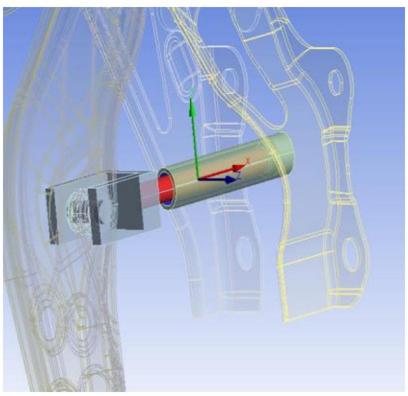

Fig. 5. Piston-Cylinder used in the analysis

### *2.3 Finite Element Analysis*

The stress analysis is carried out using Ansys Workbench© v15.0 commercial finite element analysis software. The stress distribution on the pedal surfaces is shown in Fig. 6. The location of the maximum stress concentration region is detected on the weakest part of the pedal shown in Fig. 7. Equivalent von Mises stress distribution on the full model and the stress alteration for each pedal design is computed. Maximum value of von Mises stress at the critical region is computed as 155.8 MPa.

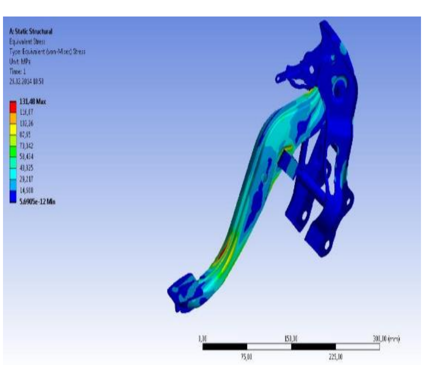

Fig. 6. Stress distributions on brake pedal

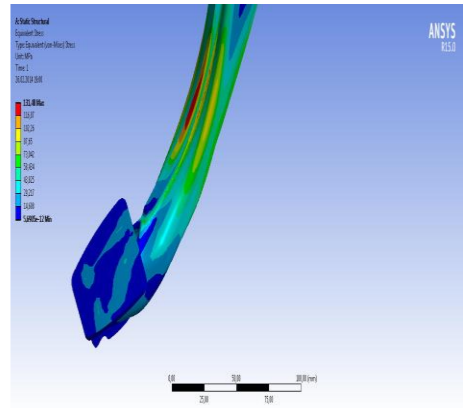


Fig.7. Critical stress region of brake pedal via stress analysis

## 3. Fatigue Life Prediction

In order to predict the fatigue life of the brake pedal, stress life method is chosen [8]. It is known from literature that fatigue analysis that use this method and static equivalent von Mises stresses obtained from the finite element analysis provide a reasonable estimation of the fatigue life of the steel-based mechanical parts. Results of the fatigue life analysis of 1.2-1.2 mm brake pedal are shown in Fig. 8.

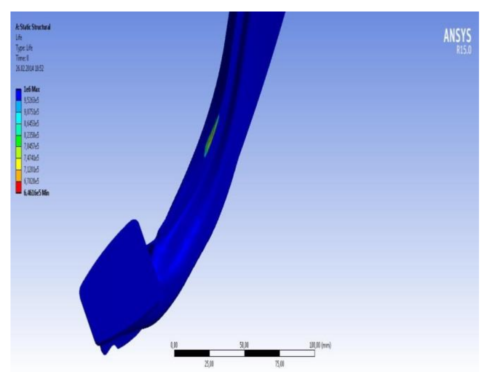


Fig. 8. Critical region of 1.2-1.2 mm brake pedal via fatigue life analysis

## 4. Pre-Results and Discussion

Finite Element Analysis shows that fatigue failure occurs at the critical regions which were seen on static stress analysis. Results of all pedal designs' fatigue life results are shown in Table 2. According to fatigue failure analysis 1.2-1.4 mm and 1.2-1.2 mm brake pedals' fatigue life are less than 1.000.000 cycles. In order to enhance the fatigue life of the brake pedal, it is necessary to decrease the stress concentration at the critical regions.

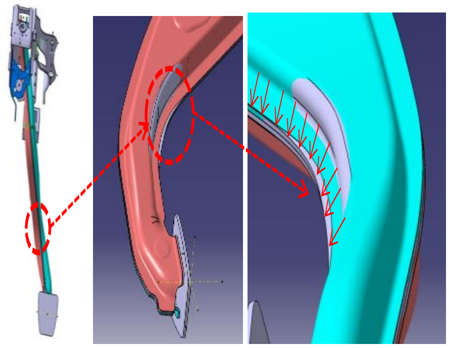

Fig.9. The revision section of the brake pedal

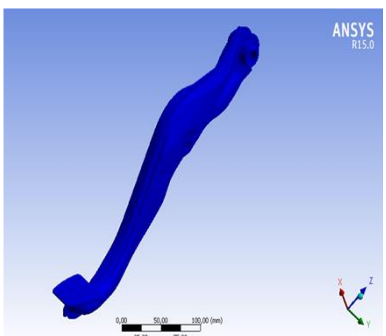


Figure-10 1.2-1.2 mm revised pedal via fatigue life analysis

As a result of static stress analysis of the revised brake pedal, the maximum stress value is found to be 131.39 MPa and it is less than the first design's (non-revised version) stress value. To reduce the stress concentration and improve the fatigue life, the design of the pedal geometry should be modified.

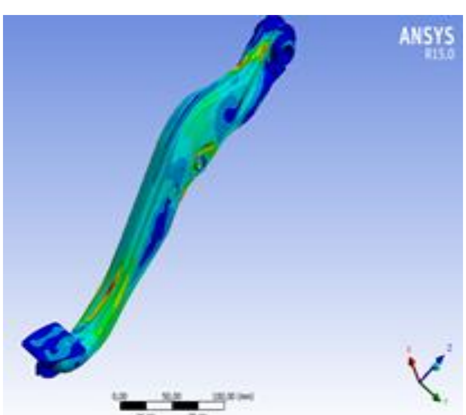


Figure- 11 Stress distribution on brake revised pedal

The basis of these results, the brake pedal has been amended in order to strengthen the design and the location of the highest stress distribution was changed. In the static stress and fatigue analysis of the revised design of the brake pedal, the pedal has followed the procedures applied in the previous analysis.

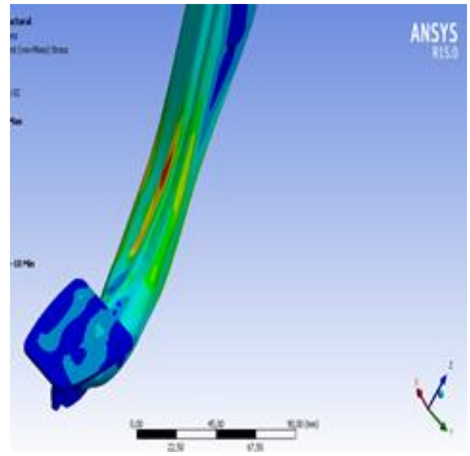


Figure-12 Critical stress region of revised pedal

Table 2. Fatigue Life Cycles of All Brake Pedal Designs

| | 8 mm | 1.4-1.4 mm | 1.2-1.4 mm | 1.4-1.2 mm | 1.2-1.2 mm |
|---|---|---|---|---|---|
| **Fatigue Life Cycles** | 1.000.000 | 1.000.000 | **646.350** | 1.000.000 | **646.000** |
| **Fatigue Life Cycles (After Revision)** | 1.000.000 | 1.000.000 | **1.000.000** | 1.000.000 | **1.000.000** |
| **Maximum von- Mises stress** | 107,46 MPa | 131,48 MPa | 141,36 MPa | 154,7 MPa | 154,71MPa |

In Fig. 9, the revision made on pedal design is seen. Stress distribution on the revised pedal surfaces is shown in Fig. 11. The location of the maximum stress concentration region is detected on the revised section of the pedal shown in Fig. 12.

## 5. Experimental Setup

The experimental validation is achieved utilizing a single cylinder (pneumatic) pedal test rig. In the test rig, the force is generated using a pneumatic cylinder (SMC©) and measured by a load cell (ESIT©), while the deflection of the pedal is detected utilizing a precise linear potentiometer (OPKON©). The specifications of the measurement devices are presented in Table 3 and Table
4 respectively. The photograph of the test rig is visible in Fig. 13. Toyota regulations dictate that the fatigue life test is run for 1.000.000 cycles. The force is applied as a symmetric square wave of which push and release periods are equal. The force which is applied to the pedals is measured utilizing load cell and fed back to the controller to ensure that the force always follows the reference.

Table 3. The specifications of Esit load cell

| | | |
|---|---|---|
| **Max. capacities (Emax)** | kg | 500 |
| **Accuracy (OIML R60)** | | C3 |
| **Combined error** | % | ≤±0.02 |
| **Minimum load** | %Emax | 0 |
| **Maximum safe overload** | %Emax | 150 |
| **Stretching (Emax)** | mm | =0.4 |
| **Max excitation voltage (Umax)** | V | 15 |
| **Operating temperature range** | °C | -40...+80 |
| **Load cell material** | | Stainless Steel |
| **Sealing (EN60529)** | | IP68 |

Table 4. The specifications of Opkon potentiometer

| | | |
|---|---|---|
| **Measuring range** | mm | 50-800 |
| **Life** | cycle | 100 million |
| **Excellent repeatability** | mm | <0.01 |
| **Resistance** | kOhm | 5-10 |

A closed loop control scheme including a classical PID controller is employed to keep the applied force to be as it is requested for the test. Furthermore, with deflection of the pedal the normal force which is applied is changing. The algorithm in the controller adjusts the level of the pressure in the cylinder to avoid mishaps if the deflection of the pedal is close to fracture level.

The mid-test pictures of the tested pedal after 250000, 500000 and 1.000.000 cycles are presented in Figs. 14,15,16 respectively. As visible in these figures no cracks were observed which was validating the theoretical design.

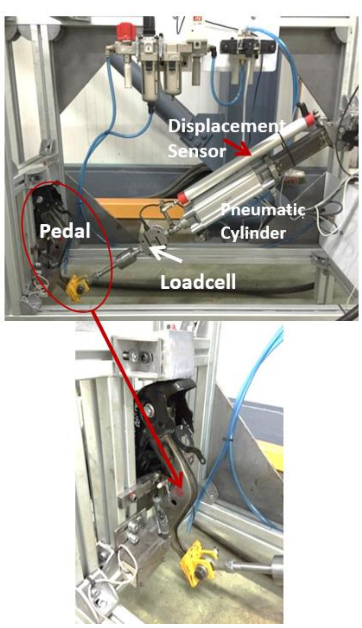


Fig. 13. The brake pedal test rig

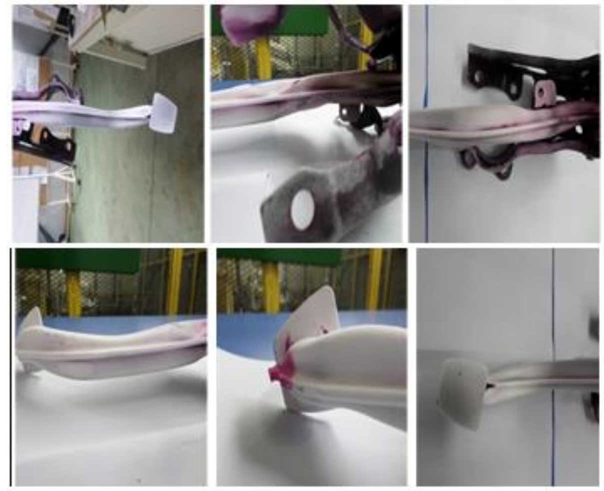

Fig. 14. The pictures of the designed pedal after 250.000 cycles.

Fig. 15. The pictures of the designed pedal after 500.000 cycles

Fig. 16. The pictures of the designed pedal after 1.000.000 cycles

## 6. Conclusion

The strength analysis of the five different brake pedal design is studied using finite element analysis. This analysis presented that fatigue failure regions on the pedal are coinciding with the higher stress concentration areas in the design as it is expected. The analysis revealed that crack initiation occurs at the highest stress concentrated regions which are the thinnest neck of the brake pedal which also has the most bending torque. In order to predict the minimum number of operations of the brake pedal without a crack, stress life approach is used with the S-N diagram of the material of the pedal which is derived by the manufacturing company. Gerber approach is used to predict the fatigue life of the pedal. It may be conducted that the fatigue analysis based on the static stress analysis and stress life approach provides a reasonable estimate of the fatigue life of the brake pedals.

It is obvious that to increase the fatigue life of the brake pedal, it is necessary to decrease the stress concentration at the critical regions. The design of the pedal geometry is modified to reduce the stress concentration and improve the fatigue life, and after the computer analysis and real tests were conducted under the requirements of the standards for the validation. As a result, 12% weight reduction is occurred and a bulky and heavy brake pedal is replaced with a lightweight and strong design which was beneficial in terms of reducing for both the car weight and the consumption of the raw materials. In future, lighter hybrid pedals will be used in automotive industry [9]. The test bench is good enough to test the new generation hybrid pedals.

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