# Design, Optimization and Reliability of Magnesium Safety Vehicle Parts

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## 1 Abstract

This paper describes the development of three interior safety parts, airbag housing, steering wheel and seat component from preliminary design to commercial mass production. For all the parts the development process includes loading characterization material selection and testing, static and dynamic nonlinear finite element analyses, prototype diecasting production, x-ray examination and static, impact and fatigue acceptance tests for reliable parts. The design optimization is then considered to reduce weight as well as price production. The optimization results are discussed as a function of diecasting parameters, mechanical properties of specimens that were taken from different critical part zones, x-rays and fatigue tests. Development and design recommendations are presented based on the above experience and study.

**Keywords:** Design, Magnesium alloys, Interior safety parts, Optimization, FEM Analysis.

## 2 Introduction

The applications of Magnesium alloys have been extended in the last decade to various vehicle parts, and a similar growth has been expected for future interior vehicle components [1]. The above is based on improvements in diecasting processes [2], mechanical properties and means of detecting casting defects. The interior safety parts of the vehicle are exposed to random dynamic loads created by the vehicle's driving conditions and the impact loads generated in the course of accidents. In conjunction, the requirements will include reliable resistance to the above loads, with an adequate energy absorption potential.

This paper sums up the development of three interior safety parts which include - airbag housing, steering wheel and seat component, from initial design to commercial mass production. In the development process, load characteristics, material selection, finite element analyses, prototype casting, detection of casting defects and final acceptance tests were made, as specified in previous papers [3], [4]. In the above mentioned development process the following differences were measured between: the calculated and the measured stresses, the theoretical properties of the materials and those actually measured on the cast products, as well as the impact of the casting defects on the fatigue tests. In the aforesaid paper these differences and impacts are discussed. Finally, a cautious process of optimization is dictated, especially in relation to fatigue loads.

## 3 Preliminary Design, Material Selection and FEM Analyses

In the first design stages the application of the load characteristics and the mechanical properties of the selected materials enabled an initial calculation and finite element analyses for geometric definition of the parts. The designed interior safety components are as shown in figures 1-3.

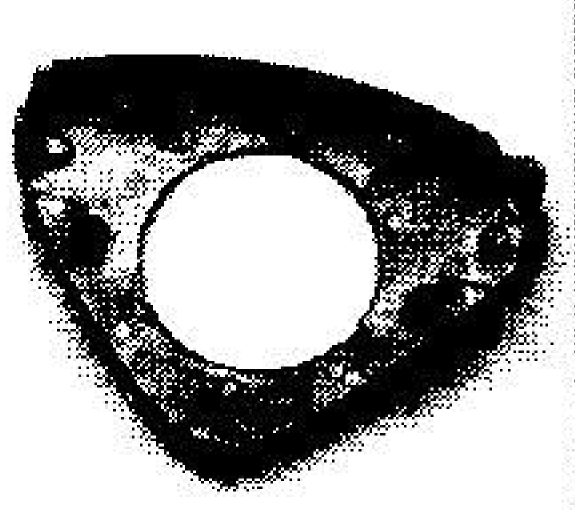

**Figure 1:** Airbag housing

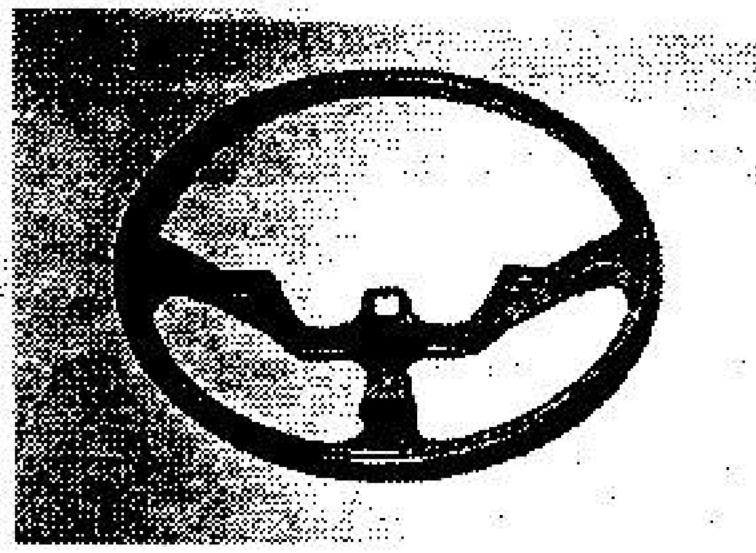

**Figure 2:** Steering Wheel

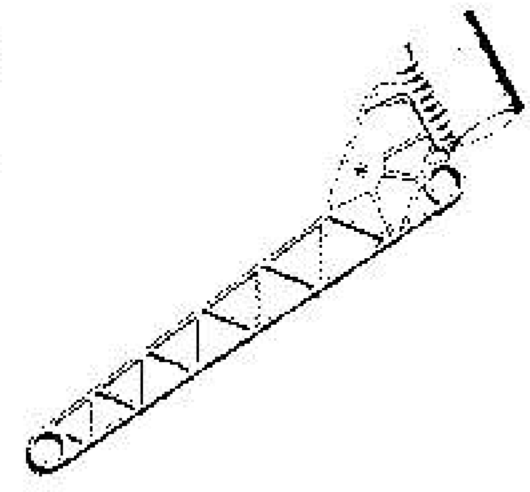

**Figure 3:** Seat beam

The load characteristics in these parts are divided as following:

1. Operation loads - Dynamic random loads created by the manner of the vehicle driving which expose the part to fatigue.
2. Impact loads - Developed in the course of an accident and dictate energy absorption requirements from the part during plastic deformations.
3. Static loads - Express the assembling and removal forces of the part or extreme loads

from (1) or (2) evaluated for the design requirements.

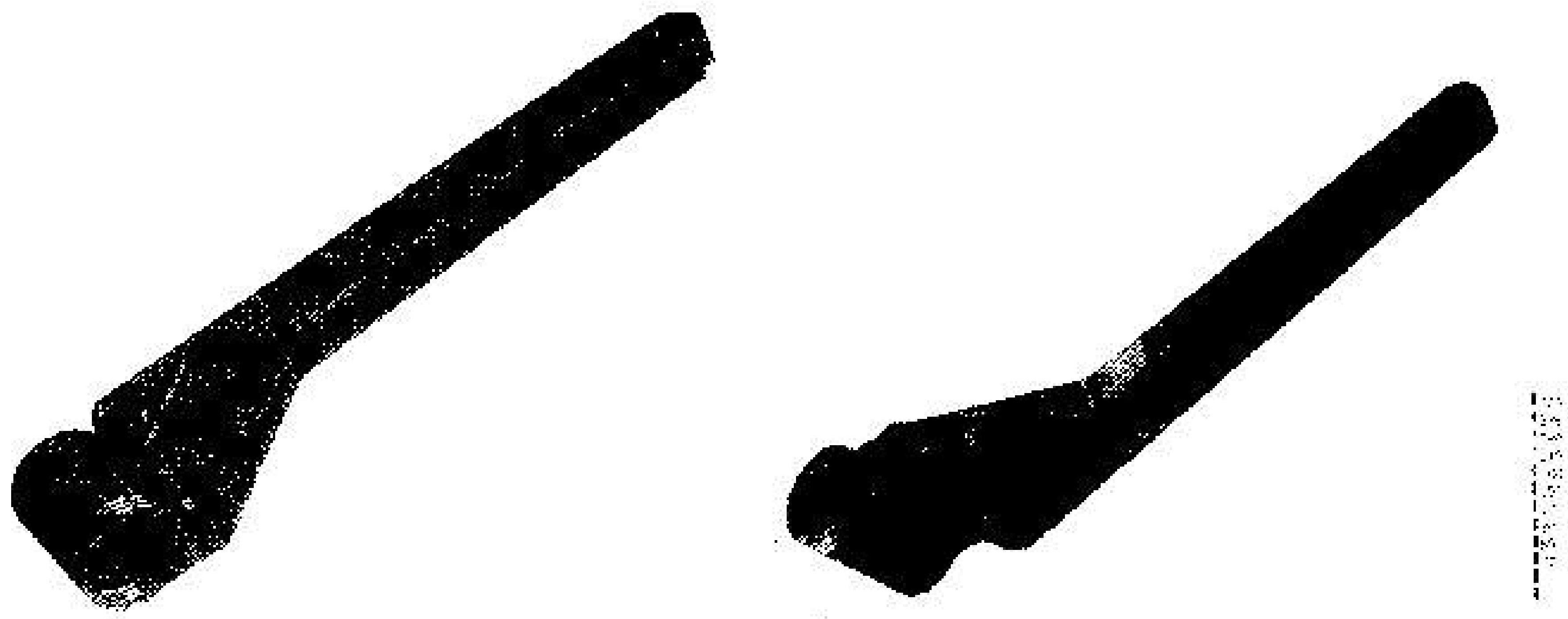

**Figure 4:** Seat beam FE model and stress distribution

Normally, in the design processes, as well as in the aforesaid case, most stress analyses were performed while using static loads which signify defined dynamic states and the dynamic analyses for the completion of the part behavior. In both cases, the loads are not identical to the real loads, and the stress analyses serve as a tool for a relative improvement of the design and characterization of the critical areas as first stage in the process of optimization. Table 1 represents the material selection and some of the mechanical properties as declared by the manufacturer for various parts. Figure 4 demonstrates the model and stress distribution of the seat beam as well as indicates the critical zones of high stresses.

**Table 3:** Test results of mechanical properties taken from AM60 seat beam different locations.

| Specimen identification | Location | unlimited tensile strength [Mpa] | Tensile yield strength [Mpa] | Elastic modulos [Gpa] | Elongation [%] |
|---|---|---|---|---|---|
| Prototype-1 | Top | 147 | 114 | 44 | 1.4 |
| S-6R4 | Bottom | 123 | 101 | 26 | 0.9 |
| Prototype-2 | Top | 168 | 109 | 34 | 3.3 |
| S-62L1 | Bottom | 157 | 105 | 34 | 2.8 |
| Prototype-3 | Top | 193 | 106 | 38 | 6.1 |
| S-16L | Bottom | 155 | 97 | 35 | 4 |

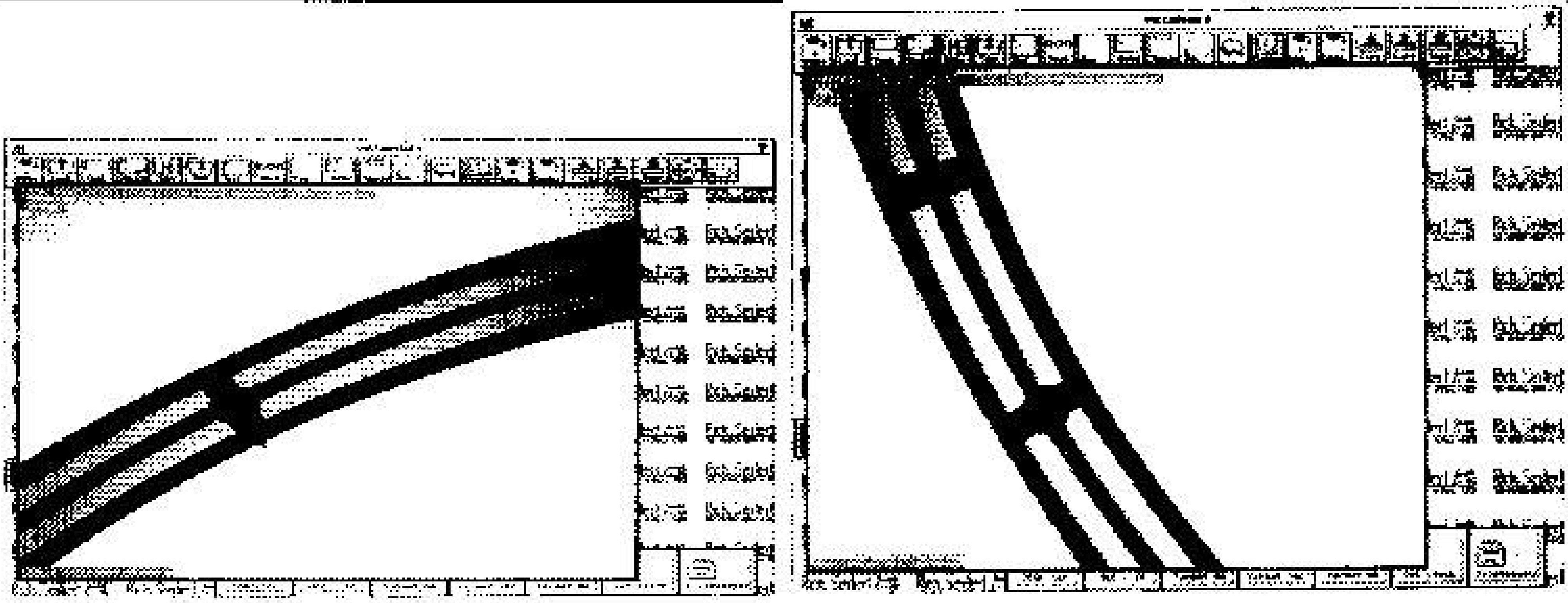

**Figure 5:** A typical description of the defects in the ejector pin points

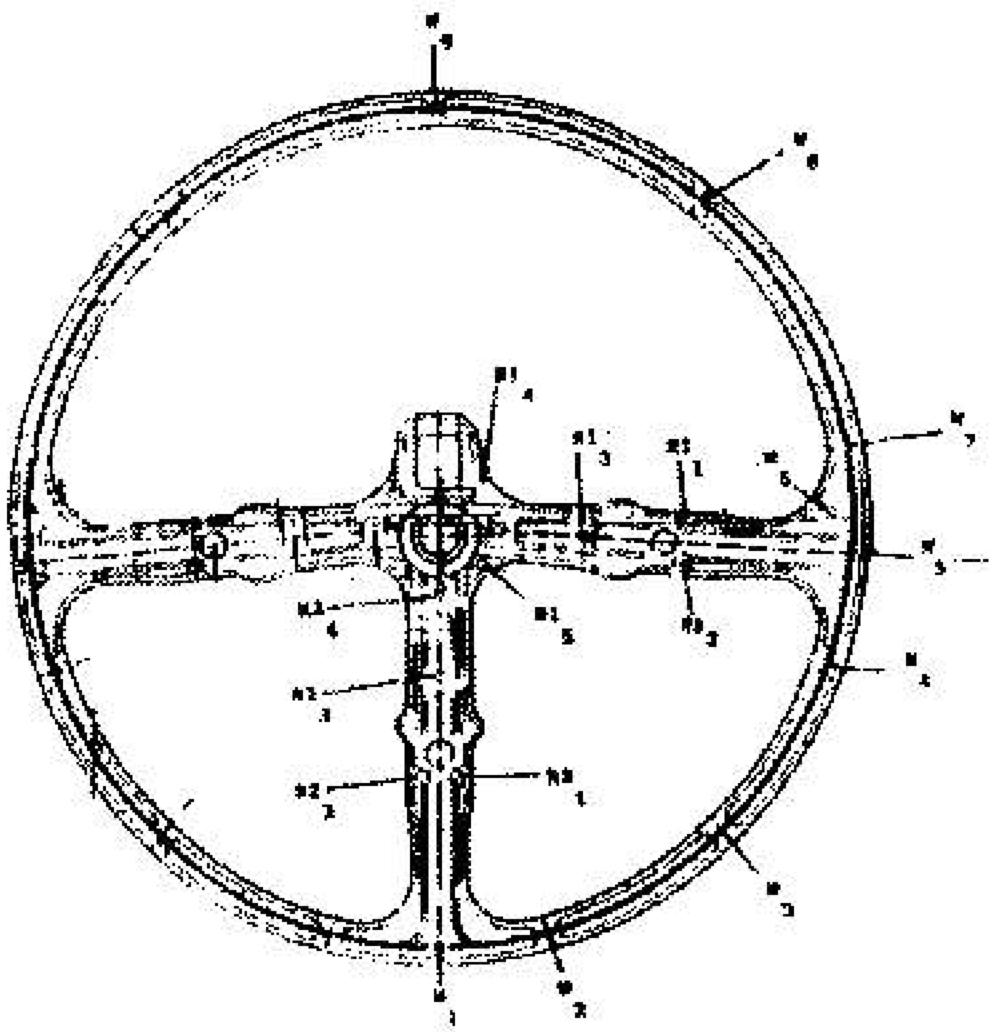

**Figure 6:** Location of the ejector pin points in the steering wheel

**Table 1:** Material selection and some of the mechanical properties at room temperature

| Part | Material selected | Ultimate tensile strength [Mpa] | Tensile yield Strength [Mpa] | Elongation [%] |
|---|---|---|---|---|
| Air bag housing | AM50 | 210 | 125 | 10 |
| Steering wheel | AM50 | 210 | 125 | 10 |
| Seat beam | AM60 | 225 | 130 | 8 |

## 4 Prototype Casting Process Development

Developing the casting processes for the prototypes of the above parts included the diecasting die and the various casting parameters. In the development the MAGNA software was applied to study the pressure effects, flow of material, temperature, material entrance and cooling duct. Table 2 summarizes the casting methods and a number of iterations to obtain casting at a sufficient quality.

**Table 2**: The casting machine, number of cavities and casting improvement iterations

| Part | Casting machine | No. of cavities | No. of iterations |
|---|---|---|---|
| Airbag housing | Frech DAW 500 ton – hot chamber | 3 | 8 |
| Steering wheel | Frech DAW 500 ton – hot chamber and vacuum | 1 | 5 |
| Seat beam | Buhler, SCD-84,840 ton - cold chamber | 1 | 3 |

For the purpose of defining sufficient quality the cast parts were tested, as following:

Micro-structure tests, density measurement, X-ray tests, hardness measurement tests, mechanical properties tests and static loading tests for each part. From our experience, the most effective tests were mechanical properties and part loading tests. For density, hardness and micro-structure, no correlation was found with the casting quality, beyond the basic level. However, significant differences were obtained in the mechanical properties in different regions of the part, affected by the casting parameters. Table 3 demonstrates the mechanical properties in the casting process improvement stages of the seat beam - in the top and bottom part of the beam.

Usually in x-ray tests extensive use is made for quality control of the part, but one should remember the limitation of size and orientation of defects that are detectable.

In addition, not all the detected defects are critical, For example, in developing the steering wheel, the x-ray tests indicate defects at the ejector pin points of the steering wheel as described in Figure 5.

The possibility that these defects will develop especially during fatigue crack growth and cause failure, depends on the nature of loading and the location of these points. In order to assess the effect of the defects, analyses of axial and radial loading were performed, and the stresses in the ejector points area were calculated using finite element method. The results showed that the stresses in their areas are significantly lower than the maximum stresses in the critical points in the steering wheel, which leads to the inference that the failure in the fatigue will also develop in the structural critical areas and not in the ejector points. Figure 6 describes the location, and Table 4 describes the maximum stresses in the various ejector points.

**Table 4:** Stress calculation in the area of the ejector pin points described in Figure 6

| Point No. | Max stress [MPa] at various axial wheel loads 400 [N] 12 o'clock | 400 [N] 3 o'clock | 800 [N] 12 o'clock | 800 [N] 3 o'clock |
|---|---|---|---|---|
| $W_1$ | 20 | 30 | 30 | 10 |
| $W_2$ | 10 | 25 | 50 | 50 |
| $W_3$ | 20 | 25 | 20 | 20 |
| $W_4$ | 30 | 30 | 30 | 50 |
| $W_5$ | 50 | 45 | 10 | 20 |
| $W_6$ | 60 | 45 | 30 | 50 |
| $W_7$ | 50 | 25 | 50 | 50 |
| $W_8$ | 20 | 20 | 20 | 20 |
| $W_9$ | 40 | 20 | 50 | 20 |
| $R1_1$ | 20 | 30 | 20 | 20 |
| $R1_2$ | 20 | 30 | 20 | 20 |
| $R1_3$ | 30 | 20 | 20 | 20 |
| $R1_4$ | 50 | 50 | 10 | 20 |
| $R1_5$ | 50 | 50 | 10 | 20 |
| $R2_1$ | 10 | 10 | 20 | 10 |
| $R2_2$ | 10 | 20 | 20 | 10 |
| $R2_3$ | 20 | 20 | 40 | 40 |
| $R2_4$ | 20 | 20 | 10 | 10 |

Therefore the x-ray tests, especially the mechanical properties test and the part loading tests constitute an additional important stage in the optimization process of the final prototype.

## 5 Prototype Static, Impact and Fatigue Tests

The physical tests that complete the acceptance tests of the final prototype development should express the types of the existing and the required loads, whereas the permissible stresses and deformations dictate the limit of the optimization process. In these components, while the airbag housing was mainly tested under the impact load, the steering wheel and the seat beam were required to meet the static forces, the impact loads and various fatigue tests. Figure 7 describes the results of the fatigue tests that were performed on the first and final prototypes of the steering wheel, and demonstrates significant improvements in the results.
Table 5 specifies the permissible stresses and deformations, which were used in the process of optimization of the various parts and the results on the prototype weight. In all the discussed cases, the first prototype failed during the tests. The results also demonstrate that the prototypes of the airbag housing and the steering wheel after optimization have a larger weight by about 10% than the initial prototype. The main reason is due to the fact that the initial design adopted a light weight and low stiffness components. However, this slight addition in weight enabled the part to meet the demands and improve the performances, including fatigue.

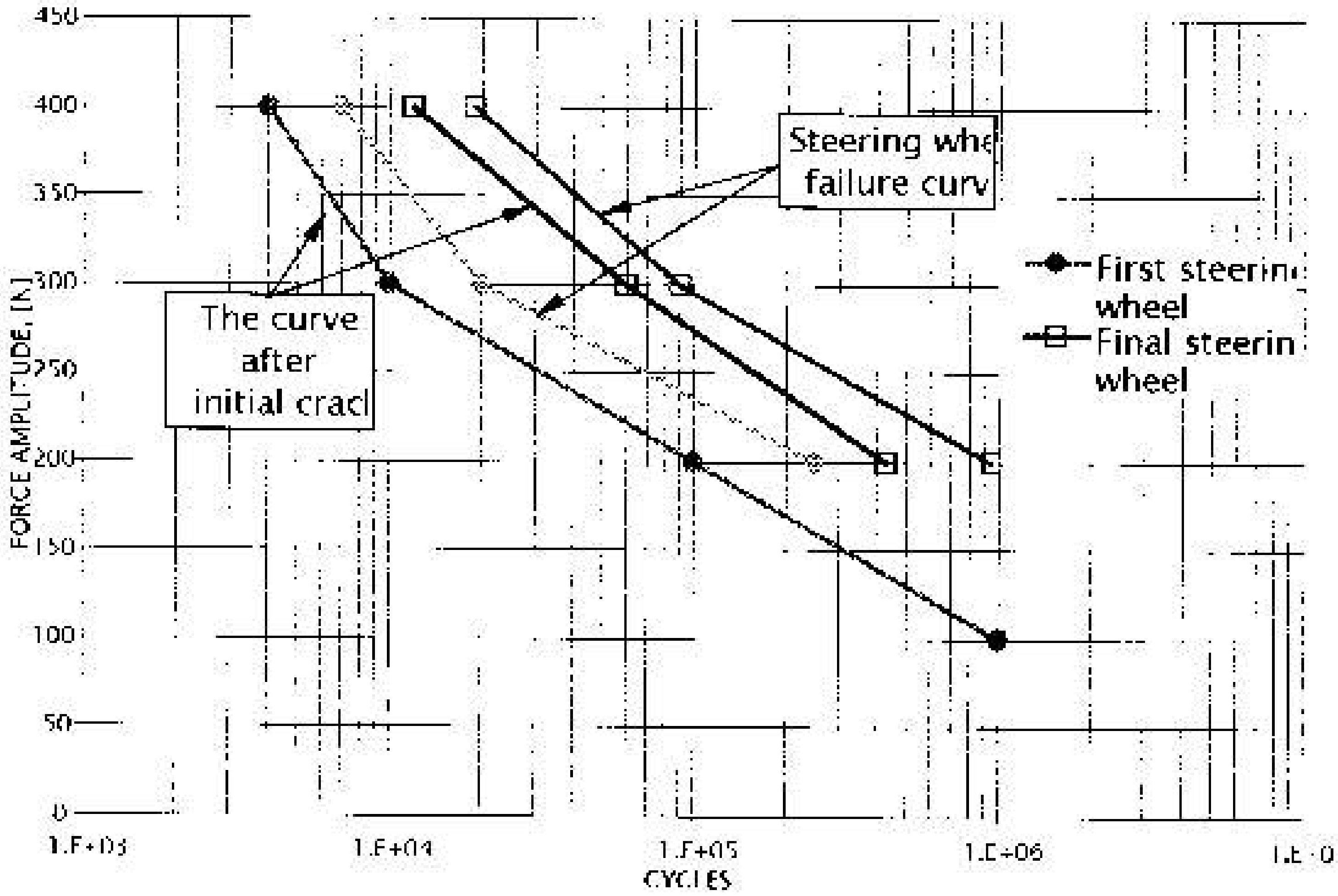


**Figure 7:** Fatigue test results for the first and optimized steering wheel

**Table 5:** Optimized prototypes compared to the first design for the different parts

| Part | First prototype weight [kg] | Max. permissible stress [Mpa]/ deformation [%] measured or calculated | | | Optimized prototype weight [kg] |
|---|---|---|---|---|---|
| | | Static test | Impact test | Fatigue | |
| Airbag housing | 0.120 | - | Plastic deformation 2% | - | 0.135 |
| Steering wheel | 0.450 | 80 MPa | Plastic deformation 4% | 60 MPa | 0.480 |
| Seat beam | 0.750 | 80 MPa | Plastic deformation 3% | 50 MPa | 0.690 |

## 6 Summary

Design and optimization for obtaining a reliable product of Magnesium alloy AM60-AM50 which was used in the framework of developing an airbag housing, a steering wheel and a seat beam, requires a process that includes:

- Design, selection of materials and finite element analyses.
- At this stage one should take into consideration that the obtained stresses and deformations are not accurate due to the estimated loads, and the variation in the mechanical properties of the cast part.
- development of a casting process to arrive at a part of better quality.
- An iterative process which is assisted in its first stages by micro-structure , density and x-ray tests, but for further improvement, tests of the mechanical properties of samples taken from the part (if possible) and load tests for the whole part should be performed.
- Static, dynamic and fatigue load tests.

- Testing the components by using loads which can express the existing and required loads from safety standards and limitation of permissible stresses and deformations.

This process was able to demonstrate reliable airbag housing, steering wheel and seat beam components that met all the requirements. In general, the process can increase the weight of the part, in case the first prototype is under-designed, yet, in conjunction, it will improve the performance of the part accordingly.

## 7 References


[1] Friedric H., Schumann S., The Second Age of Magnesium - Research Strategies to Bring the Automotive Industry's Vision to Reality. Magnesium 2000, Proceedings of the second Israeli International Conference on Magnesium Science & Technology, Dead Sea, Israel 2000, pp 9-18.

[2] Fink R., Beck W., Optimization of the Magnesium Die Casting Process. Magnesium 2000. Proceedings of the second Israeli International Conference on Magnesium Science & Technology, Dead Sea, Israel 2000, pp 112-119.

[3] Tzabari Y., et al., Design and Modification of Magnesium Airbag Housing. Magnesium 97, Proceedings of the First Israeli international Conference on Magnesium Science & Technology, Dead Sea, Israel 1997, pp. 373-379.

[4] Tzabari Y., et al., Light Weight and Low Stiffness Magnesium Steering Wheel Design. Magnesium 2000, Second Israeli international Conference on Magnesium Science & Technology, Dead Sea, Israel 2000, pp. 35-42.