Lightweight design of automobile frame based on magnesium alloy

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Abstract. The structural performance and lightweighting of car base frame design is a challenging task due to all the performance targets that must be satisfied. In this paper, three kinds of materials (iron, aluminum and magnesium alloy) replacement along with section design optimization strategy is proposed to develop a lightweight car frame structure to satisfy the tensile and safety while reducing weight. Two kinds of cross-sections are considered as the design variables. Using Ansys static structure, the design optimization problem is solved, comparing the results of each step, structure of the base flame is optimized for lightweight.

1. Introduction
In recent years, The measures of reducing CO₂ and the development of EV vehicle has been developed rapidly. In addition to the aging society and adapt to the problem of the elderly and children ikuo user ultracompact and lightweight electric vehicle.

According to the research [1,2], the fuel consumption can be reduced by 6%-8% and the emission volume can be reduced by 5%-6%, which is 10% of the vehicle weight loss. Therefore, vehicle lightweight is an important measure to save energy and reduce pollution. Magnesium alloys have the advantages of high specific strength, strong energy absorption, good formability and recovery, and have a wide application in the field of automobile. [3]

In order to reduce the weight of the car, this study uses a new type of magnesium alloy material applied to a car chassis structure, without changing the original structure, by changing the car frame girder section and materials, so that achieving the purpose of reducing the weight of the frame along with contenting the stress intensity of magnesium alloy frame.

2. Analysis methods and theories
The choice of the test lightweight material has to be made in the context of the design requirements and the load spectrum imposed to the structure. The lightweight potential has to be shown within constraints given by the material itself, the useable designed space and the manufacturability of real parts. An overall cost estimation should not be reduced to the material itself, and it should also consider
production, assembly, tooling, maintenance and other cost. Accordingly, it should reflect its proper share on the total cost of ownership to the customer.

In this research, there is a goal of designing an automobile base frame lighter than a commercial frame. Design variables for weight reduction are material constants such as material density and plate thickness. Therefore, the optimal design of this time is to make it safer and lightweight. In the optimum design, static structural analysis is carried out while adjusting the parameters and thickness of the material, and the parameter which becomes even better by using lighter weight material and thickness while comparing with the weight of the base frame we predicted and performed the following static structural analysis.

In this research, in order to guarantee the safety within the elastic range of the base frame of the automobile, it is determined by two discrimination criteria and the optimum design is performed.

The material strength is determined by using the Tresca hypothesis (maximum shear stress theory) which is often used for material dynamics [4-7]. That is, it is safe if the difference between the maximum principal stress and the minimum principal stress is smaller than the tensile strength of the material.

\[ \sigma_s = \frac{1}{2} (\sigma_1 - \sigma_2) < \sigma_{\text{max}} \] (1)

Here, \( \sigma_s \) is the main shear stress, \( \sigma_{\text{max}} \) is the maximum shear stress, \( \sigma_1 \) is the maximum principal stress, and \( \sigma_2 \) is the minimum principal stress.

Depending on the Mises yielding condition when plastic deformation occurs, the homologous stress (Mises stress) can be expressed by the following equation.

\[ \bar{\sigma} = \frac{1}{\sqrt{2}} \left[ (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]^{1/2} \] (2)

For safety discrimination using static structural analysis within the elastic deformation range, the Mises stress of the structure is smaller than the yield stress \( \sigma_y \) at the time of occurrence of plastic deformation, \( \bar{\sigma} \leq \sigma_y \).

3. The analysis process

3.1. Material editing and loading

In this paper, three kinds of materials are used for the analysis and calculation of automobiles (table 1). In the whole base frame of gravity condition, the 40% percent of the loading is in the first half of the frame, and remaining 60% loading is acting on the rest of the frame, and the supporting force in the hub link is loading chassis upward, making the car balance.

| Table 1. The mechanical properties of Aluminum, Steel and Magnesium. |
|-----------------------------|------------------|------------------|
|                            | SPFH540         | Aluminum 6061-T6| Magnesium AZ91 |
| Density (kg/m³)            | 7850            | 2700             | 1830            |
| Coefficient of elasticity (GPa) | 210            | 69               | 45              |
| Poisson ratio              | 0.3             | 0.33             | 0.35            |
| Yield strength (MPa)       | 355             | 276              | 160             |
| Tensile strength (MPa)     | 540             | 310              | 340             |

After selecting the material, the stress analysis of the model is carried out, figure 1. Firstly, the load of the different parts of the model is restrained after the freedom of the end face is restrained.
3.2. Meshing and analysis
In the choice of materials and loading after the needs of the model grid, then choose the size of the grid, to the small number of mesh complex (30–40 mm), the simple model can be set up a relatively large number of grid (40–70 mm). In this paper, we use 50 mm mesh to simplify the calculation, as shown in figure 2. After the grid is divided, the analysis and calculation can be carried out.

4. Example analysis of car model
In this study, the market is the target frame to design a lightweight vehicle base frame. Therefore, the optimal design of safety while satisfying the lightweight. In the optimum design, structural analysis, static, while adjusting the cross-sectional shape and material parameter, structure and material adopted by lightweight design method, and in addition, the structural static analysis, the parameters such as Von-Mises stress and deformation are predicted and are shown in figures 3 through 5.

Figure 1. Boundary condition of Base frame model.

Figure 2. Mesh of Base frame model.

Figure 3. The calculation results of Steel base frame. (a) Von-Mises and (b) Deformation quantity.
Figure 4. The calculation results of Aluminum base frame. (a) Von-Mises and (b) Deformation quantity.

Figure 5. The calculation results of Magnesium base frame. (a) Von-Mises and (b) Deformation quantity.

Table 2. Simulation result.

|                | Square Type |          | I Type |          |
|----------------|-------------|----------|--------|----------|
|                | H b         | Fe (355 MPa) | Al (276 MPa) | Mg (160 MPa) | H b         | Fe (355 MPa) | Al (276 MPa) | Mg (160 MPa) |
| Weight (kg)    |             |           |        |           |             |           |        |           |
| △L max (mm)    |             |           |        |           |             |           |        |           |
| (σ1−σ3) max (MPa) |         |           |        |           |             |           |        |           |
| Type           |             |           |        |           |             |           |        |           |
| Weight         | H b         | Fe (355 MPa) | Al (276 MPa) | Mg (160 MPa) | H b         | Fe (355 MPa) | Al (276 MPa) | Mg (160 MPa) |
|                | 80 mm       |           |        |           |             |           |        |           |
|                | 6 mm        |           |        |           |             |           |        |           |
|                | 7 mm        |           |        |           |             |           |        |           |
|                | 90 mm       |           |        |           |             |           |        |           |
|                | 6 mm        |           |        |           |             |           |        |           |
|                | 7 mm        |           |        |           |             |           |        |           |


| Weight | 100 mm | 5 mm | 4 mm | 100 mm | 5 mm | 6 mm | 7 mm | 4 mm | 6 mm |
|--------|--------|------|------|--------|------|------|------|------|------|
| 275    | 245.3  | 290  | 1.446| 1.781  | 1.698| 1.313| 1.131| 1.448| 276.47|
| 84.4   | 414.1  | 99.7 | 24.2 | 187.4  | 2.43 | 3.312| 174.9| 4.246| 266.47|
| 64.3   | 413    | 67.6 | 1.47 | 178.9  | 4.983| 5.042| 173.8| 5.616| 62.12 |
|        |        |      |      |        |      |      |      |      |      |
| △L_{max} (mm) |        |      |      |        |      |      |      |      |      |
| (σ_{1}−σ_{3})_{max} (MPa) |        |      |      |        |      |      |      |      |      |
| (σ_{1}−σ_{3})_{max} (MPa) |        |      |      |        |      |      |      |      |      |

Under the above conditions, the model of the base frame is analyzed and calculated, and the shape variables, maximum and minimum stresses of the model are obtained (figures 3-5). Through the analysis and calculation of the chassis with different sectional area, the stress, deformation and weight ratio are obtained (table 2), and achieved the purpose of optimizing the chassis.

5. Conclusion
In this paper, a new method in analysing automobile base frame were carried out using the Ansys Workbench. The results can be obtained, when the section is I type (H=100, b=5), the light weight of the car frame is realized under the condition of satisfying the stress. And the results show that Magnesium alloy frame is 70% lighter than iron frame, 40% lighter than aluminium frame, and the lightweight design was achieved.

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