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Discrete Material and Thickness Optimization of Seat Cushion Frame under Dynamic Condition

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Abstract
Automotive seats are one of the representative automotive parts that require weight reduction while satisfying safety requirements. Some methods consider both strength and weight to reduce the weight of seats, but it is difficult to apply them to all parts considering both the number of parts and their costs. For the weight reduction of the seat frame, methods for analyzing the impact on strength and weight and applying different materials and thicknesses to each part depending on the impact level can be considered.

In this study, a method of determining commercially available materials and thicknesses by applying the discrete material and thickness optimization method under a dynamic load condition that considers the FMVSS 214 regulation was proposed for the standard automotive seat frame provided by NHTSA.

Through the first optimization, seven parts having a significant impact on the results were selected. Through the second optimization performed using the selected main parts as parameters, materials were finally determined and a weight reduction of 18% was achieved. The validity of the proposed method was verified by comparing the weight of the model before and after optimization. Hypermesh was used for finite element modeling, and LS-Dyna was used for basic analysis and optimization.

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1. Introduction

From an energy efficiency and environmental point of view, the weight reduction of automobiles is an important issue in the automobile industry. As automotive seats are in contact with passengers, they significantly affect the ride comfort and safety of passengers. In addition, the weight of seats accounts for 3%–5% of the total vehicle weight due to the increase in the number of safety and convenience parts, and this makes the seat frame the target of weight reduction. Therefore, the automotive seat frame must satisfy both weight reduction and strength requirements.

Several studies have been conducted by changing materials[1-3], modifying geometry[4-5], and adjusting thicknesses to address weight reduction[6-7]. However, considering cost reduction and moldability, which are first considered for material selection in the automobile industry, relatively expensive high-strength lightweight materials cannot be applied to all parts. In addition, advanced high-strength steel (AHSS) has limited thickness for

March - April 2020
ISSN: 0193-4120 Page No. 4584 - 4592

manufacturing and few studies have dealt with this problem. In recent years, discrete material and thickness optimization (DMTO), an approach to optimize laminated composite structures by discretizing the material and thickness parameters, has been used for weight reduction[8-10].In this study, basic analysis was conducted by simulating the dynamic situation of the FMVSS 214 regulation, and weight reduction optimization was performed by applying the DMTO method and performing optimization twice.

2. Finite Element Analysis

The materials used in this study and the boundary conditions and finite element model used for the basic analysis are described as follows.

2.1. Material properties

The materials used were steel, which is most commonly used as a structural material, high-strength steel (HSS), and AHSS, which is made using the hot stamping method.

Figure 1 shows the standard tensile test setup in accordance with the ASTM standard. The data obtained through the test were expressed in a true strain–stress graph as shown in Figure 2, and the mechanical properties of the materials are shown in Table 1.

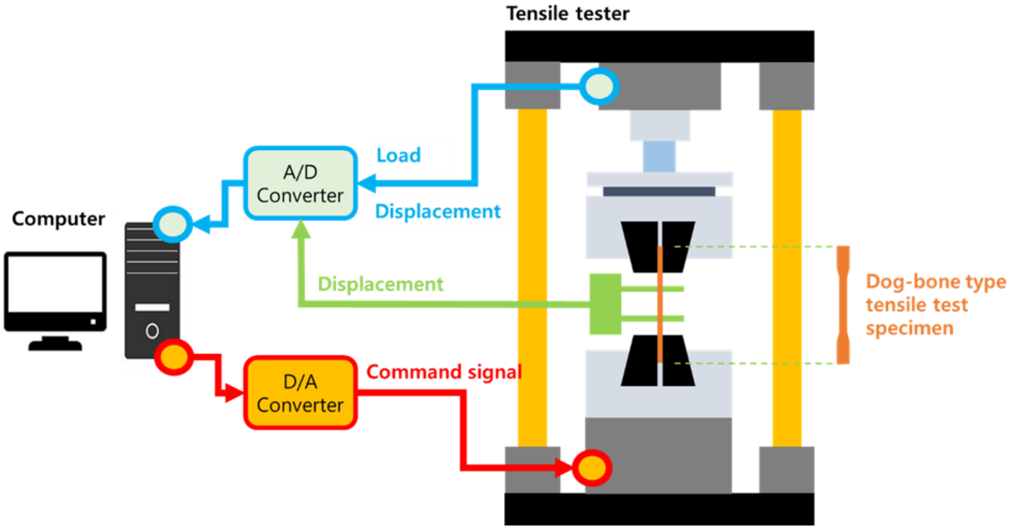


Figure 1. Tensile test setup

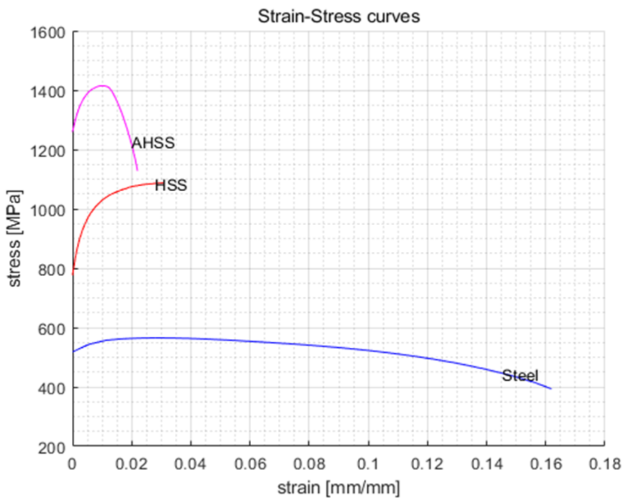


Figure 2. Strain–stress curves for steel, HSS, and AHSS

Table 1 : Mechanical properties of the materials

Symbols	Units	Steel	HSS	AHSS
E	MPa	210,000	210,000	210,000
$\boldsymbol{\nu}$	-	0.35	0.35	0.35
$\boldsymbol{\sigma_y}$	MPa	518	767	1253
$\boldsymbol{\varepsilon_y}$	-	0.0025	0.0037	0.006
$\boldsymbol{\sigma_{UTS}}$	MPa	587	1120.9	1714.4

2.2. Finite element modeling

The Honda Accord 2017 seat provided by NHTSA was modeled using Hypermesh. Figure 3 shows the finite element model of the seat frame. Table 2 shows the composition of the seat frame. The seat frame mainly consists of a seat back unit, cushion unit, and rail unit. In this study, only the cushion and rail units, which account for approximately 56% of the total seat weight, were considered. The elements were constructed using 5 mm 2D shells, which are favorable for reducing the analysis time.

Figure 3 Finite element model of the seat frame

Table 2 : Composition of the seat frame

No.	Part	Component (ea)	Weight (%)
1	Seat back	23	44
2	Seat Cushion	12	37
3	Rail	12	19

2.3. Finite element analysis

The explicit solver of LS-Dyna was used for finite element analysis. Figure 5 shows the simulation of the FMVSS 214 load shown in Figure 4 on the seat cushion frame[11-13]. An initial velocity of 29 km/h was applied to the side pole. In the basic analysis step, the properties of steel and a thickness of 2 mm were applied to all parts.

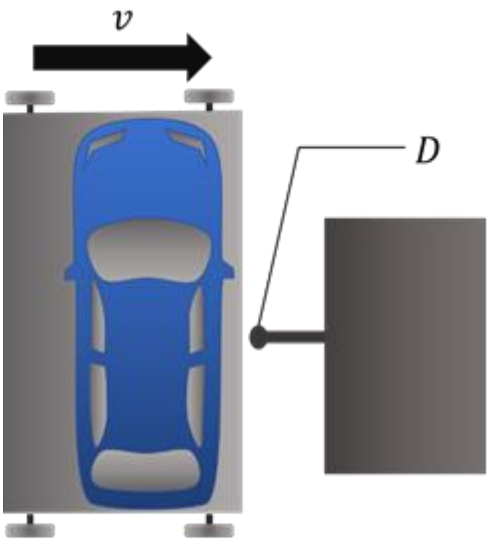
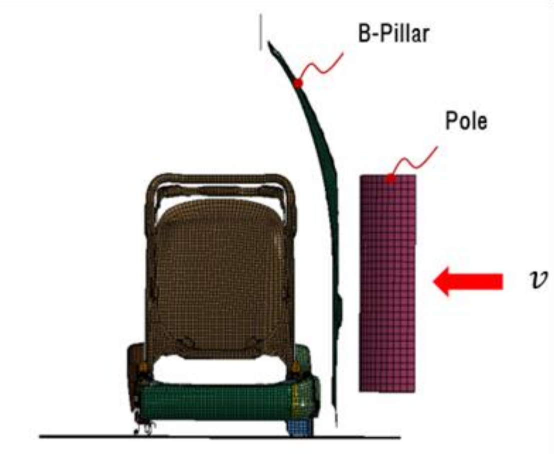


Figure 4. FMVSS 214 test environment

(a)



(b)

Figure 5. Finite element model reflecting the FMVSS 214 regulation (a) ISO view (b) Front view

Table 3 : FMVSS 214 regulation overview

Regulation	Analysis type	$v\,[km/h]$	D [mm]
FMVSS214	Dynamic	29	254

The displacement of the pole over time obtained from the basic analysis is shown in Figure 6. The maximum displacement of 187 mm occurred at 0.05 ms

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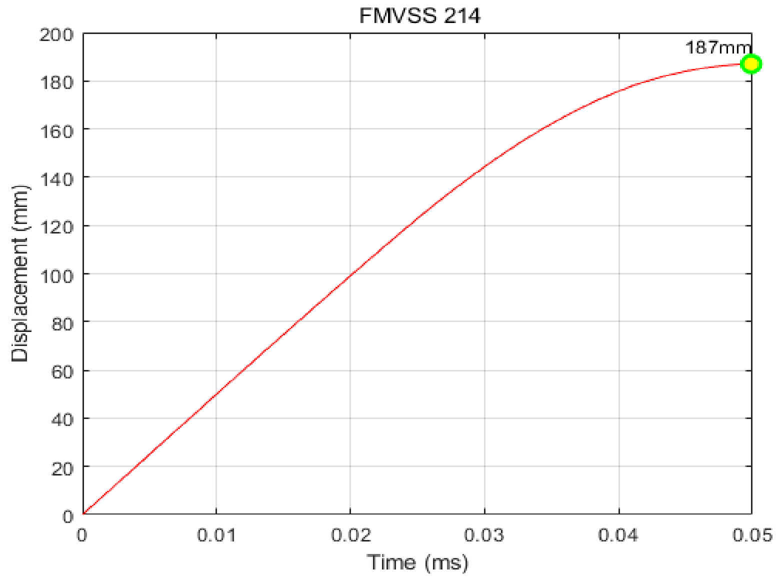

Figure 6. Results of the basic analysis reflecting the FMVSS 214 regulation

3. Discrete Material & Thickness Optimization

In this research step, the DMTO optimization method was performed twice. In the first optimization, the main parts that affect weight and strength were selected. The second optimization was performed using the materials and thicknesses of the selected parts as parameters.

3.1. First optimization

The parameters to be used for optimization were three material levels (steel, HSS, and AHSS) and four thickness levels (0.5, 1.0, 1.5, and 2.0 mm) for 24 parts in the cushion and rail units. As several case studies must be conducted before optimization, LatinHyperCube design of experiments was used to reduce the number of cases. As the basic setting of LS-OPT proceeds toward minimizing all the design parameters, the IDs of 1, 2, and 3 were given to steel, HSS, and AHSS, respectively, to minimize the determination of AHSS, a relatively expensive material. The maximum displacement of the pole, i.e., 187 mm, was set as the constraint. The objective function was weight minimization. This optimization process is shown in Figure 7.

TEST Engineering & Management
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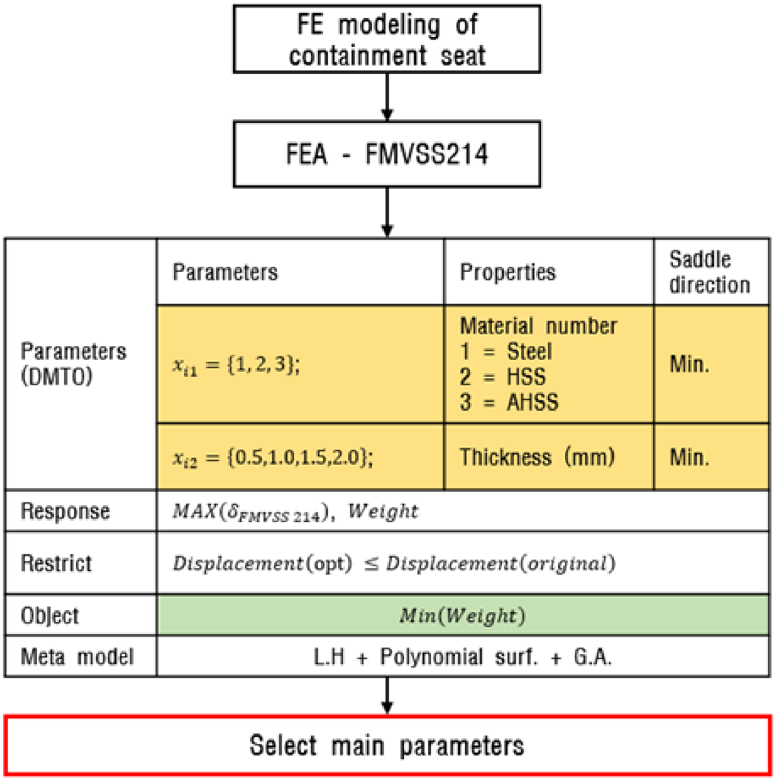
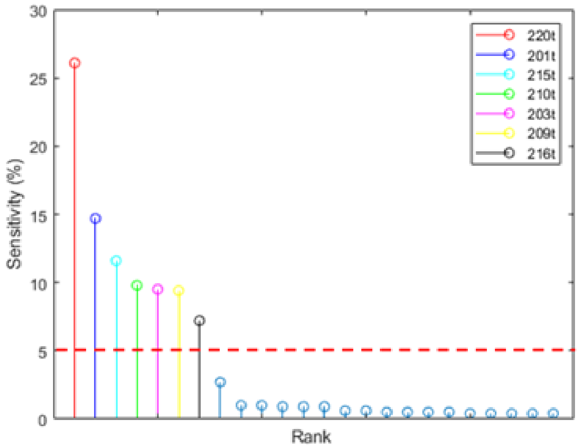


Figure 7. Optimization process

Figure 8(a) shows the results of the sensitivity analysis. Seven parts were selected, and factors for which the influence of strength and weight was less than 5% were excluded. Figure 8(b) shows the geometry of the selected parts. Finally, the results of the first optimization are shown in Table 4. HSS and AHSS were applied to six of the seven parts. The weight was 8.3 kg, which was approximately 28% lower than the previous weight of 11.5 kg.



(a)

March - April 2020
ISSN: 0193-4120 Page No. 4584 - 4592

(b)

Figure 8. (a) Sensitivity analysis results; (b) parts selected through sensitivity analysis

Table 4: Materials and thicknesses of the main parts

Material	Parts[No.]	Thickness[mm]
Steel	216	0.5
HSS	201	2
AHSS	203	2
	209	0.5
	210	1
	215	0.5
	220	2

3.2. Second optimization

The second optimization was performed similarly using only the seven parts selected in the first optimization as parameters. Table 5 shows the results of the second optimization.

As steel was selected for more parts than in the first optimization, the use of expensive AHSS was minimized. It was observed that parts 203, 209, and 215 in Table 5 must use AHSS in the dynamic situation. Table 6 shows the values before optimization and the results of the first and second optimizations. The final weight reduction effect was 18%. Although the effect was lower compared with the first optimization result, the strength was higher and the use of high-strength *materials could be minimized.*

March - April 2020
ISSN: 0193-4120 Page No. 4584 - 4592

Table 5: Materials and thicknesses of the main parts selected through the second optimization

Material	Parts [No.]	Thickness [mm]
Steel	201	2
	210	2
	216	0.5
	220	2
AHSS	203	2
	209	0.5
	215	1.0

Table 6: Values before optimization and the results of the 1st and 2nd optimizations

Type	Weight [kg]	Displacement [mm]
Before optimization	11.5	187.4
1st optimization	8.3	192.8
2nd optimization	9.4	188.2

4. Conclusion

The purpose of this study was the weight reduction of the seat cushion and rail frame. The thicknesses and materials of 24 parts were considered for optimization. In general, studies on thickness optimization have been conducted in a continuous manner within a specific boundary. When thickness optimization is performed thus, ideal results can be obtained, but post-processing is required at the manufacturing stage. Therefore, optimization was performed using four available thickness levels by applying DMTO, an approach to optimize laminated composite structures by discretizing the material and thickness parameters.

In the first optimization, seven main parts were derived and their materials and thicknesses were selected. The results of the second optimization were different from those of the first optimization. The weight reduction effect decreased, but the strength was higher and the number of the parts that used high-strength lightweight materials decreased from six to three. This indicates that the optimization results will vary if there are more iterations of optimization.

As for the load condition, a dynamic test condition in accordance with the FMVSS 214 test regulation was considered. Although a full car model was not implemented, a weight reduction effect was observed. Therefore, a similar tendency is also expected in a full car model.

In this study, only steel materials were considered. If nonferrous metals are also considered, it will be possible to obtain clearer results. Future research will deal with problems that occur during the bonding of discrete materials when the materials of the frame optimized through the application of the DMTO method are different for each part.

5. Acknowledgment

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