Finite Element Analysis and Optimization of Automotive Seat Floor Mounting Bracket in Metal Forming Using LS-DYNA

Mayur Mane[1], Dr. Somnath Kadhane[2]

[1]*ME Design Engineering Student at SVPM's College of Engineering Malegaon, Maharashtra, India*
[2]*Associate Professor, Mechanical Dept. of SVPM's College of Engineering, Malegaon, Maharashtra, India*

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Abstract - *In this research, variables such as blank holder force, friction coefficient and die shoulder radius in sheet forming process of automotive seat floor mounting bracket were discussed together with its formability. Defects occurring during the forming process are emphasized using CAE tool explicit dynamic software LS-DYNA. The solutions to such defect problems will also be given along with various methods used for the analysis and optimization for defect free process are explained.*

Key Words: Automotive seat floor mounting bracket, Metal forming, CAE, LS-DYNA

1. INTRODUCTION

Sheet metal forming (SMF) is a process where pieces of sheet metal are modified to its geometry rather than removing any material. In sheet metal forming process where a material, knows as the blank is formed by stretching it between a punch and a die.

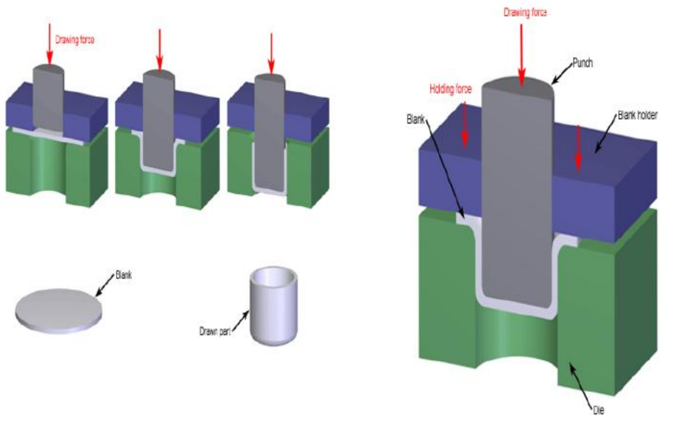

Fig -1: Sheet metal forming [2]

1.1 Automotive Seat Floor Mounting Bracket

Seat floor mounting bracket is used to mount the seating system in the vehicle as shown in figure 2. These brackets support to the seating system and hold the seat rigidly in place and also prevent it from shifting around. Automotive seat floor mounting bracket has a complex shape. The forming process of the automobile parts generally include drawing, trimming, stamping, shaping, flanging, and other processes. In case of seat floor mounting bracket, it has to go through two processes namely deep drawing and stretching.

In order to get qualified forming of automotive seat floor mounting bracket to meet Customer requirements, multiple modifying and repeated debugging are required for forming die, forming process, technological parameters, and so forth, while "trial and error" method is used in the traditional way for repeated testing, which not only require a longer production cycle, but also require high production costs.

With the continuous development of numerical analysis technology, plastic forming theory, stamping technology, and computer technology, CAE (computer aided engineering) technology is gradually applied in forming process and die design process for automotive sheet metal parts; CAE related software are more and more widely used in die debugging process. The formability and possible defects of parts can be analyzed through the simulation, which provide the reliable basis for die debugging, so that it can reduce the die manufacturing problems, shorten the production cycle, save production costs, and offer more economic benefits for enterprises.

Fig -2: Frame of a car seat

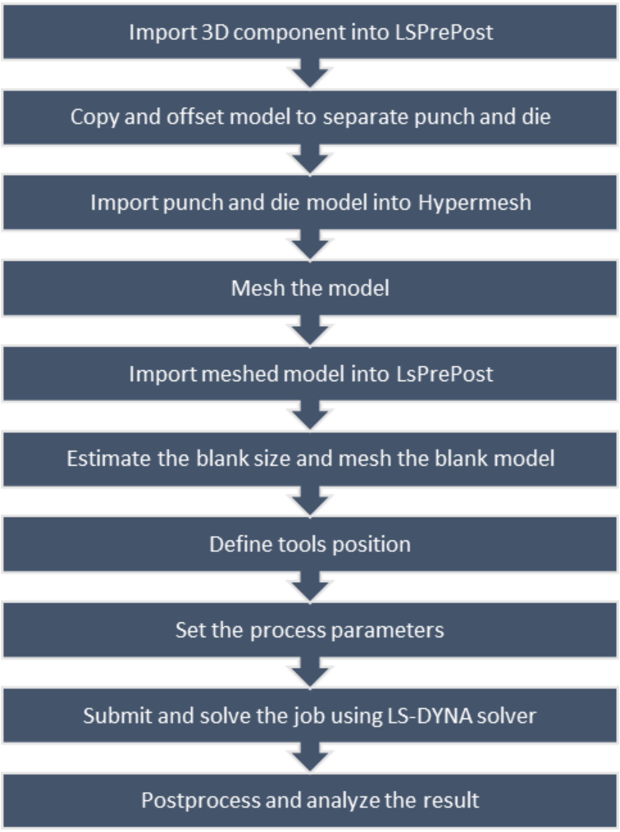

Fig -3: Flowchart of the process simulation

2. DESIGN OF BIW COMPONENT

Seat floor mounting bracket is the bracket used for mounting purpose of the seating system in the vehicle. Whole seat assembly is mounted on this seat floor mounting bracket. Figure 4 shows the isometric view of automotive seat floor mounting bracket.

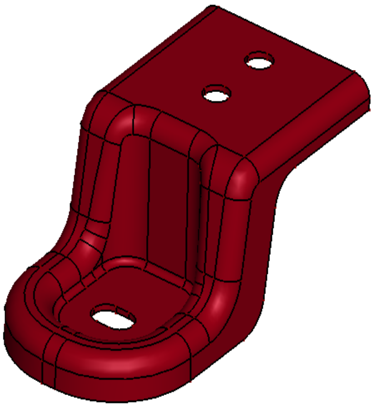

Fig -4: Isometric view of seat floor mounting bracket

Table -1: Material properties of DQSK steel

Density (ρ)	$7.9{\times}10^3$ **Kg/m^3**
Young's Modulus (E)	207000 **Mpa**
Poisson's Ratio (μ)	0.3
Yield Strength (σ_y)	179 **Mpa**
Anisotropic Hardening Parameter (R)	1.63

Here, anisotropic hardening parameter (R) is also called as a Lankford's coefficient or plastic strain ratio. It is the ratio of true width strain to the true thickness strain at a particular value of length strain.

$$R=\frac{\epsilon_w}{\epsilon_t}=\frac{\text{True width strain}}{\text{True thickness strain}}$$

It defines the ability of metal to deform in the thickness direction relative to the deformation in the plane of the sheet. When R value is greater than 1, sheet metal resist thinning and if R value is less than 1, thinning becomes the preferential metal flow direction which increases the risk of failure in forming operation.

3. FINITE ELEMENT MODELING OF AUTOMOTIVE SEAT FLOOR MOUNTING BRACKET

3.1 Punch and Die Separation from the Component

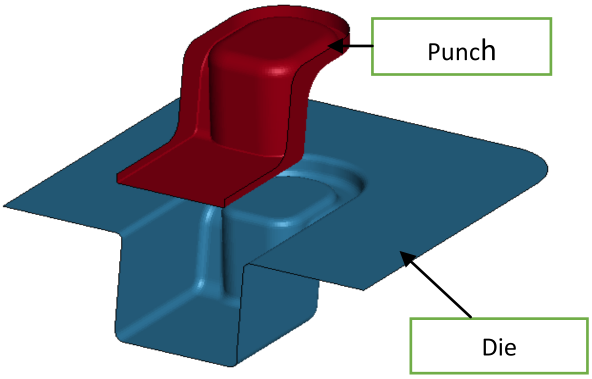

Fig -5: Offsetting punch and die from component

We have a 3D model of seat floor mounting bracket. For the purpose of forming it is necessary to have the forming tools that is Punch and die. So, we need to offset punch and die from the component. To offset punch and die from the 3D model of seat floor mounting bracket we used LS-PrePost software. Figure 5 shows the punch and die model.

3.2 Meshing of Model

The punch and die model which we separated from the component is imported in the Altair Hypermesh software and meshed the model with element size 1 mm. Meshing is done carefully that the critical corners and the small radii must be captured by the elements. That is one of the reason to keep element size 1 mm. Meshed model of punch and die is shown in figure 6.

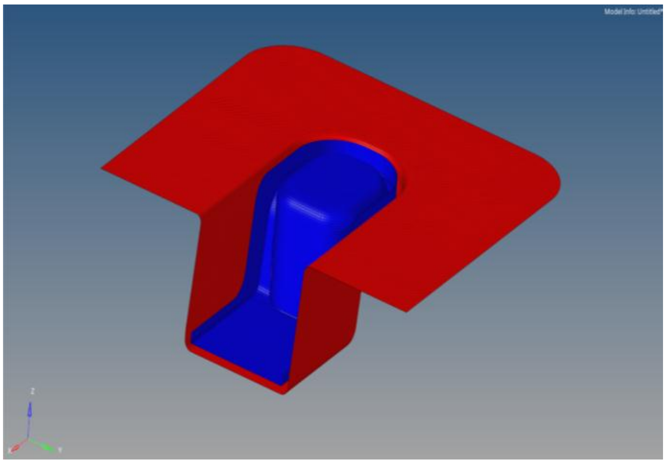

Fig -6: Meshed model of punch and die in Hypermesh

3.3 Blank Size Estimate and Blank Meshing

Producing metal parts is an intricate process and companies must find ways to reduce production costs whenever possible. Choosing the right blank size and shape can help reduce the amount of energy needed to manufacture a part and lower the waste produced.

Here we used the LS-PrePost software to estimate the blank size. We imported 3D model of the component in LS-PrePost software and then extracted the mid-surface. The extracted mid-surface is then meshed using auto-mesher command. This meshed surface of the component is then unfolded using command in the metal forming tab inside the LS-PrePost software. Figure 7 shows the developed blank in LS-PrePost software (All dimensions are in mm). This estimated blank model is then meshed using blank mesher command in LS-PrePost software. Meshed blank model is shown in figure 8.

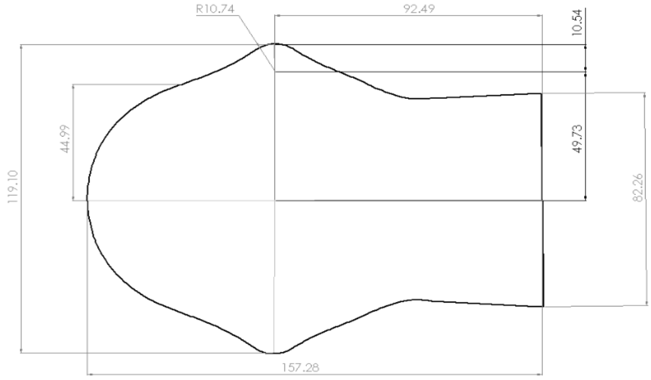

Fig -7: Developed blank in LS-PrePost software

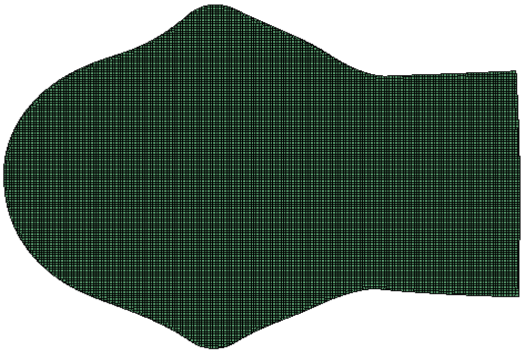

Fig -8: Meshed blank

3.4 Establishment of Simulation Analysis Model

To establish model we followed the following steps:

1. Importing the meshed punch and die model shown in the figure 6 in LS-PrePost.
2. Importing blank model shown in figure 8 in LS-PrePost software.
3. Separating blank holder from the blank.

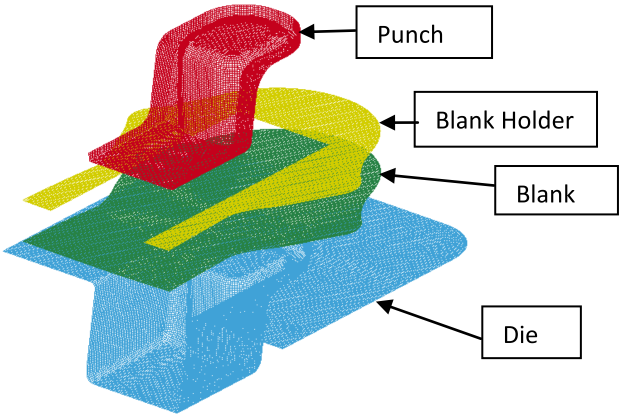

Fig -9: The FE model of automotive seat floor mounting bracket

4. SIMULATION AND ANALYSIS

To run the simulation we have to give the appropriate material model and boundary conditions to the model.

4.1 Material Model

Table -2: Material model details

Sr. No.	Material Name	Material Type
1.	MAT_TRANSVERSELY_ANISOTROPIC_ELASTIC_PLASTIC	MAT_37
2.	MAT_RIGID	MAT_20

4.2 Contact

We have used CONTACT_FORMING_SURFACE_TO_SURFACE keyword to define contact. The contact is penalty based contact. It is necessary to define three different keywords for implementing the expected three contacts are “Blank-Punch”, “Blank-Die”, “Blank-Blank Holder”.

4.3 Punch Motion

In our simulation, die and blank holder remains stationary and punch is the one that moves. Punch movement was imposed using the keyword BOUNDARY_PRESCRIBED_MOTION_RIGID. Here punch has to travel a distance of 52.13 mm downward to complete the forming operation. The punch motion is defined using DEFINE_CURVE keyword. Termination time of the process is 5 seconds.

4.4 Load Rigid Body

To give blank holder force we use LOAD_RIGID_BODY card in LS-PrePost software. In our model load is in the z direction.

4.5 Control and Database Cards

We have to define some control and database cards such as CONTROL_ACCURACY, define control parameter that can improve the accuracy of the calculation. CONTROL_SHELL, since the mesh is of shell elements it allows defining the theory describing shell behavior or how thickness changes have to be simulated. CONTROL_TERMINATION, it plays an important role because it establishes when solver has to stop calculations. The field ENDTIM is used to set the termination time. IMPLICIT_AUTO, IMPLICIT_GENERAL, these control cards are used to initiate the implicit analysis of problem. CONTROL_HOURGLASS, which prevents that in the simulation verifies “hourglassing”, i.e. anomalous deformations of the elements constituting the mesh. CONTROL_ADAPTIVE, this important keyword used to refine the mesh where computed quantities show wide changes in their values. We applied adaptive mesh refinements to the blank.

DATABASE_ASCII_OPTION, this simplifies the type of database. LS-DYNA will not create an ASCII database unless the corresponding DATABASE_ASCII_OPTION card is included in the input deck. DATABASE_BINARY_D3PLOT, this keyword contains the information about thickness or stresses on each shell element. DATABASE_EXTENT_BINARY, this keyword control to some extent the content of binary output databases d3plot, d3thdt and d3part.

5. OPTIMIZATION

Orthogonal experimental design method is used to study multiple factors level. During the sheet metal forming process the process parameters mainly affects the forming performance are BHF, die shoulder radius and friction coefficient. In our process orthogonal experimental factors were designed for the BHF and friction coefficient. Mainly, thinning and wrinkling are the major defects in the sheet metal forming process. So, the maximum thinning rate and maximum thickening rate are evaluation index as thinning rate gives us the failure of sheet because of cracks and thickening rate gives us the idea of wrinkling. After doing many runs we take die shoulder radius as 3 mm for all simulation runs. We didn’t include die shoulder radius in the orthogonal array.

Maximum thinning rate, $\Delta = \max\left(\frac{t_0 - t_i}{t_0} \times 100\%\right)$,

Maximum thickening rate, $\Delta = \max\left(\frac{t_i - t_0}{t_0} \times 100\%\right)$,

Where t_0 = Thickness of the sheet before forming

t_i = Thickness of unit *i* of sheet metal after forming

In order to ensure the product strength, maximum thinning rate should be as small as possible. Also, to avoid wrinkling in the final product, maximum thickening rate should be small.

The parameters and their levels are shown in table 3. Combination schemes of orthogonal experiment process parameters were designed by using orthogonal array L_4 (2^2) as shown in table 4.

Table -3: Factors and levels of orthogonal experiment

	Factors	
Experiment No.	A BHF (N)	B Friction Coefficient
1.	5000	0.10
2.	6000	0.12

Table -4: Scheme of orthogonal experiments

	Factors	
Experiment No.	A BHF (N)	B Friction Coefficient
1.	5000	0.10
2.	5000	0.12
3.	6000	0.10
4.	6000	0.12

5.1 Result and Analysis of orthogonal Experiment

The simulation results of process parameters schemes through the orthogonal experimental design corresponding to maximum thinning rate and maximum thickening rate were shown in table 5.

In automotive seat floor mounting bracket higher thinning exist during forming process. The areas where higher thinning exist have the greater risk of cracking. For maximum thinning rate smaller the better, and smaller the value is there is less risk of cracking. Table 6 shows the response for signal to noise ratios for thinning.

In automotive seat floor mounting bracket higher thickening also exist during forming process. The areas where higher thickening exist have the greater risk of wrinkling. For maximum thickening rate smaller the better, and smaller the value is there is less risk of wrinkling. Table 7 shows the response for signal to noise ratios for thickening.

Table -5: Thickness reduction and thickening data obtained by orthogonal experiments

	Factors		Evaluation Index	
Experiment No.	A BHF (N)	B Friction Coefficient	Maximum Thinning Rate %	Maximum Thickening Rate %
1.	5000	0.10	39.33	16.53
2.	5000	0.12	39.46	16.60
3.	6000	0.10	39.38	16.75
4.	6000	0.12	39.36	16.64

Table -6: Response table for signal to noise ratios for thinning

Level	Blank Holder Force	Friction Coefficient
1	-31.91	-31.90
2	-31.90	-31.91
Delta	0.01	0.01
Rank	2	1

Table -7: Response table for signal to noise ratios for thickening

Level	Blank Holder Force	Friction Coefficient
1	-24.38	-24.42
2	-24.45	-24.41
Delta	0.07	0.01
Rank	1	2

For the maximum thinning rate, friction coefficient is the highest influencing factor which can be changed by adding the lubricants and changing the surface roughness. BHF is the second influencing parameter and which can be modified by the adjusting the parameters of mechanical presses. Table 8 shows the ANOVA for SN ratios of thinning. Relationship between maximum thinning rate and experimental factors is shown in chart 1.

For the maximum thickening rate, BHF is the most influencing factor which can be modified by adjusting the mechanical presses. Friction coefficient has the very less contribution in the maximum thickening rate. Table 9 shows the ANOVA for SN ratios for thickening. Relationship between maximum thickening rate and experimental factors is shown in chart 2.

Table -8: ANOVA for SN ratios for thinning

Source	DOF	Sum of Squares	Mean Squares	% Contribution
Blank Holder Force	1	0.000030	0.000030	6.65
Friction Coefficient	1	0.000147	0.000147	32.59
Residual Error	1	0.000273	0.000273	
Total	3	0.000451		39.24

Table -9: ANOVA for SN ratios for thickening

Source	DOF	Sum of Squares	Mean Squares	% Contribution
Blank Holder Force	1	0.004607	0.004607	66.59
Friction Coefficient	1	0.000105	0.000105	1.52
Residual Error	1	0.002206	0.002206	
Total	3	0.006918		68.11

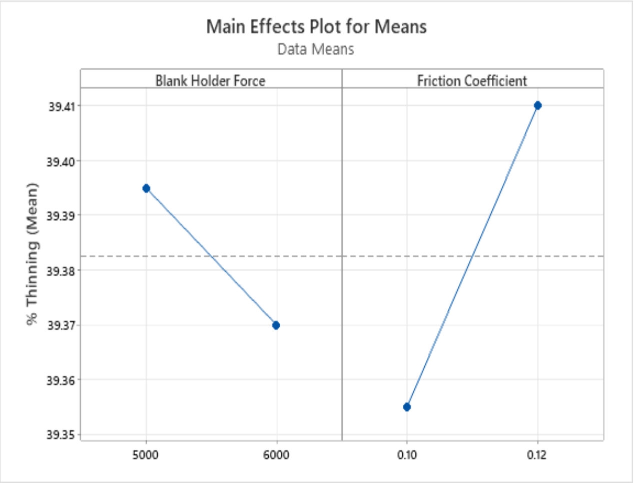

Chart -1: Relationship between maximum thinning rate and experimental factors

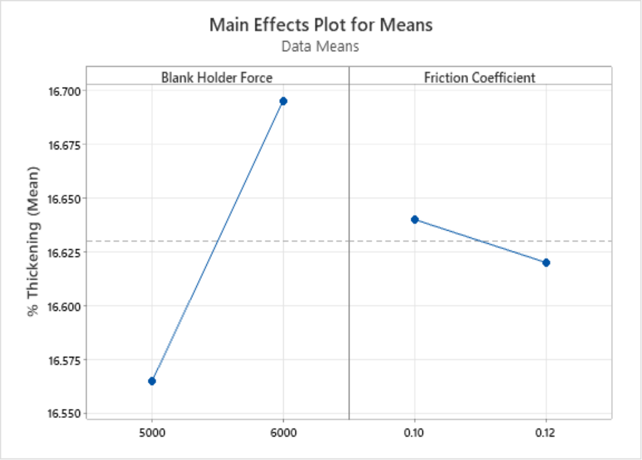

Chart - 2: Relationship between maximum thickening rate and experimental factors

So according to the optimization scheme, optimal combination of parameters for maximum thinning rate and maximum thickening rate are shown in the table 10.

Table -10: Optimum combination of parameters

Blank Holder Force	Friction Coefficient
5000 N	0.10

6. RESULT AND DISCUSSION

As we discussed orthogonal experiment scheme in table 4 their software simulation results are as follows:

6.1 Experiment No. 1

BHF = 5000 N Friction Coefficient = 0.10

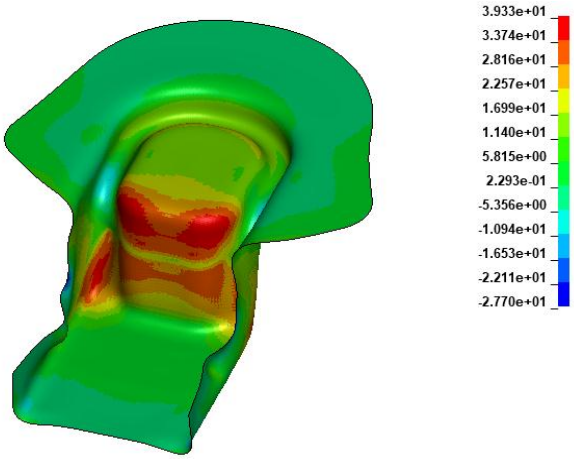

Fig -10: Percentage thinning and thickening

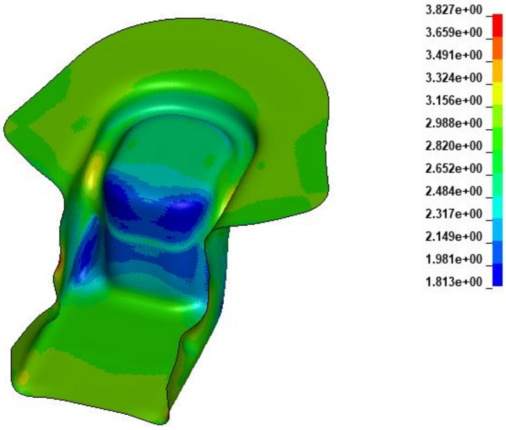

Fig -11: Thickness distribution in mm

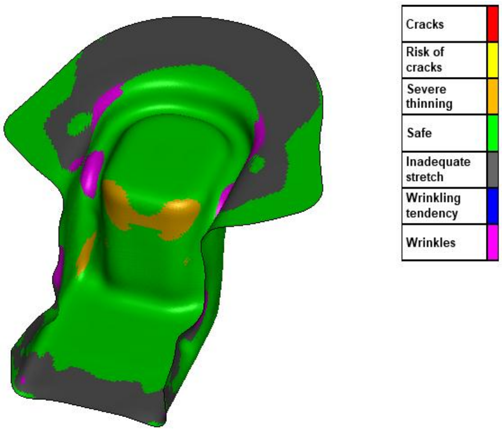

Fig -12: Formability diagram

6.2 Experiment No. 2

BHF = 5000 N Friction Coefficient = 0.12

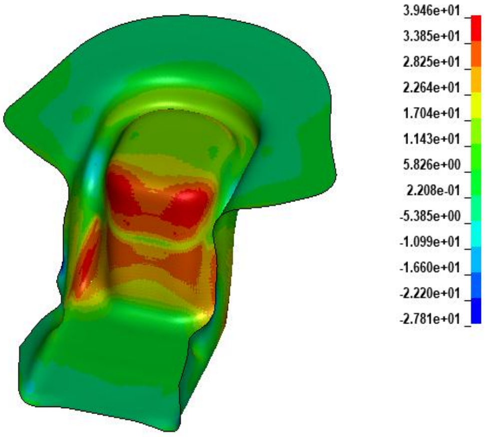

Fig -13: Percentage thinning and thickening

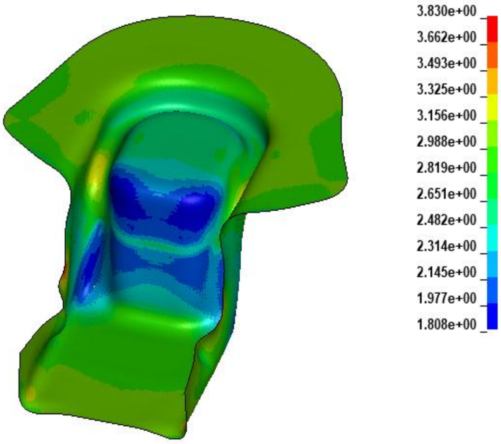

Fig -14: Thickness distribution in mm

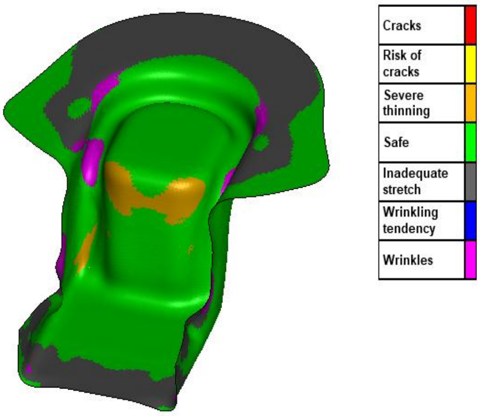

Fig -15: Formability diagram

6.3 Experiment No. 3

BHF = 6000 N Friction Coefficient = 0.10

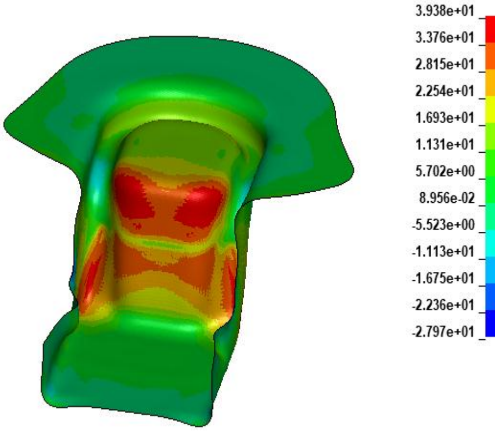

Fig -16: Percentage thinning and thickening

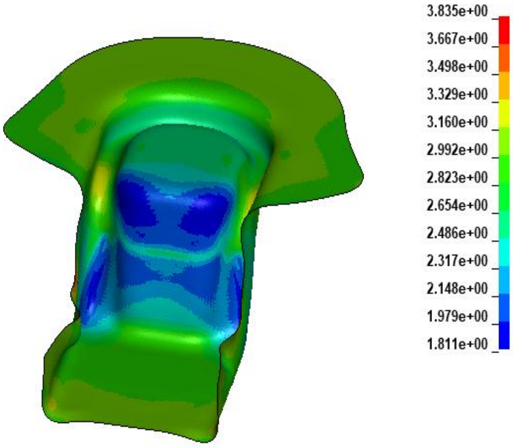

Fig -17: Thickness distribution in mm

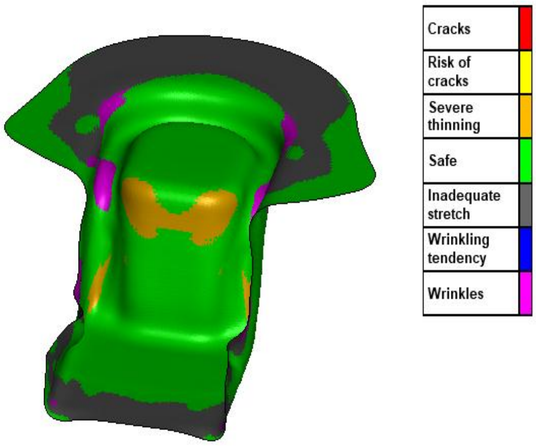

Fig -18: Formability diagram

6.2 Experiment No. 4

BHF = 6000 N Friction Coefficient = 0.12

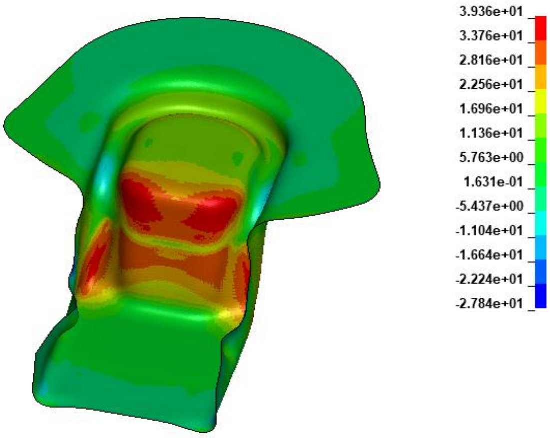

Fig -19: Percentage thinning and thickening

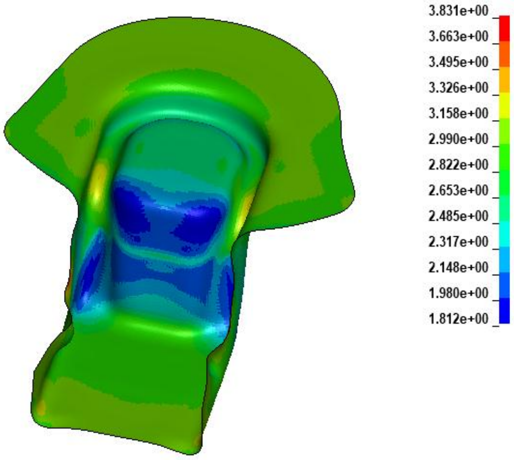

Fig -20: Thickness distribution in mm

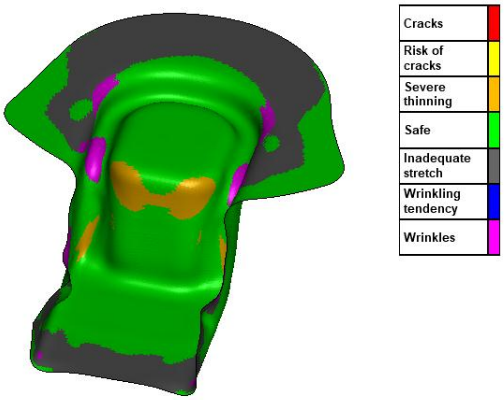

Fig -18: Formability diagram

6. CONCLUSION

In order to study the influence of several process parameters which have great influence on the forming quality of automotive parts, this study adopted automotive seat floor mounting bracket as the research object. We studied the formability of automotive seat floor mounting bracket by using LS-Dyna software and influence of process parameters on the forming quality of material used for the automotive seat floor mounting bracket. We selected the BHF, die shoulder radius and friction coefficient with maximum thinning rate and maximum thickening rate as evaluation indexes, used orthogonal experiment method for simulation analysis on the effects of these three parameters, and carried on optimization. For optimization purpose we take BHF and friction coefficient as a process parameters. It can be obtained from the experiment that the impact of the two process parameters on the maximum thinning rate from strong to weak is friction coefficient and BHF, while on the maximum thickening, the greatest impact is BHF, followed by the friction coefficient. The maximum thinning rate and maximum thickening rate could be effectively controlled through orthogonal experiment optimization, and the high quality forming parts can be obtained with less defects.

Following are the conclusions from this study:

1. We predicted the formability and defects such as thinning and wrinkling. We came to know that friction coefficient is the highest influencing parameter on the rate of thinning with 32.59% contribution and blank holder force is the highest influencing parameter on the rate of thickening with 66.59% contribution.

2. LS-Dyna software is good for setting up forming simulations.

3. A simulation software is more important for the company which wants to be a leading company in the forming domain.

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