A Study of Stamping Die Design of Autobody Part Using Software Simulation

Nanang Ali Sutisna
Mechanical Engineering Study Program
President University
Jababeka, Cikarang, Bekasi, Indonesia
nanang.ali@president.ac.id

Vicky Ghufron Afandi
Mechanical Engineering Study Program
President University
Jababeka, Cikarang, Bekasi, Indonesia
vghufronafandi22@gmail.com

Abstract*— This paper presents a study of stamping die design of car backdoor reinforcement using software simulation. The existing process of stamping die design and manufacturing in the company being observed involves seven to ten trials before getting an acceptable die and therefore increase the cost of dies. By using software, it is expected that the number of trials is reduced as the design is analyzed in advance to identify unwanted defects in stamping process, such as wrinkle, split, and springback and develop a proper die design. The scenario started with comparing a final stamped part with its design. By using 3D scanner, the final part geometry is obtained and compared with the original 3D CAD model to examine the deviation of the part from its original design. The comparison between the final stamped part and the original design shows discrepancies, it is obvious that most probably the design has been modified to prevent stamping defects. Next, the original design is simulated by applying blank holder force of 109.7 kN. The first simulation on the original design part shows that the minimum thickness strain in -14.4% and has strong wrinkle tendency, therefore the design was modified then run a simulation again on this modified design part. The modification was mainly focus on essential corner radius and increasing blank holder force to 129.2 kN to prevent wrinkle and reduce springback. The second simulation yields a good formability indicated by better forming limit diagram, safety zone, and springback, despite the minimum thickness strain was increased to -19.2%. So, by using software simulation the correct die geometry can be obtained prior to manufacture the dies as to avoid unnecessary cost of modifying the dies during the trial processes. In addition, the number of trials can be minimized resulted in shorter lead time of producing stamping dies.

Keywords*— *autobody part, design, software simulation, stamping

I. Introduction

As the automotive industry in Indonesia is growing, a demand in auto parts industry is increasing, including autobody parts. However, many auto body stamping companies in Indonesia carry out direct test during formability analysis when testing new dies. The trial may reach seven to ten times. Each trial usually requires three to seven punches to find out if there is any defect, which takes three to five days – excluding time for die modification - resulting in higher costs, time and resources. The common defects such as wrinkles, crack, excessive thinning, springback, and other forming defects often occur [1]. The die geometry plays an important role in preventing defects, particularly corner radius [1, 2]. Similarly, stamping parameter such as blank holder force significantly influences the stamping result [3, 4, 5]. The effect of the variable blank holder force on the formability was studied by Ma, et al. [6].

This study was conducted to find out a proper CAD model geometry for stamping die design by checking the formability of the design using two different model geometries, original design and modified design. The design modification is mainly done on corner radius. A software simulation was performed on both models to check the occurrence of defects and find a way to prevent them.

II. Methodology

This research begins by 3D scanning an actual finished stamped part to be compared with the original 3D CAD model and analyzed for deviations. The stamped part taken is the one that has been passed quality control process, and therefore has no defect. The next step is taking the original 3D model of the part to be simulated, then analyzing its formability. If the simulation results show that there are still tearing or wrinkle defects, the part will then be modified, by referring to the scanned geometry data, and re-simulated until good results are obtained without defects, as it is illustrated in the flow diagram in Fig. 1;

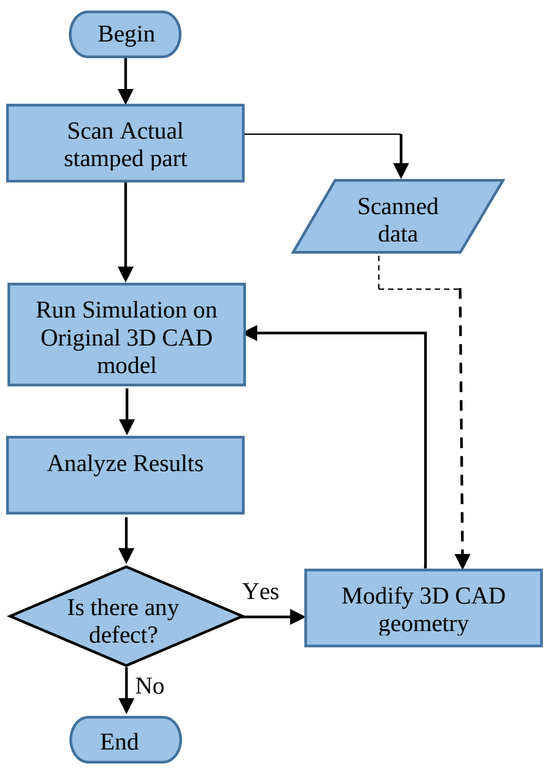
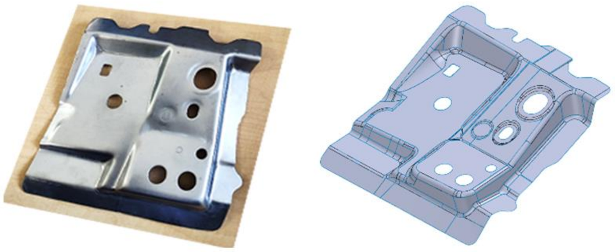


Fig. 1. Flow diagram of the study

A. Original Part Design

The part used in this research is the Backdoor Reinforcement Part (Fig. 2) using soft steel material SPCC440 (Steel Plate Cold Coil) with specifications of 1.60 x 496 x C x 209.5. The size indicates that the part has a thickness of 1.6 mm and a width of 496 mm with a coil material shape and a pitch distance of 209.5 mm.



(a) (b)

Fig. 2. (a) Actual finished part (b) Original 3D design

B. 3D Scan Process

The part was scanned using Einscan Pro 2X. The scanning process starts gradually and slowly focuses on certain areas when scanning as shown in Fig.3.

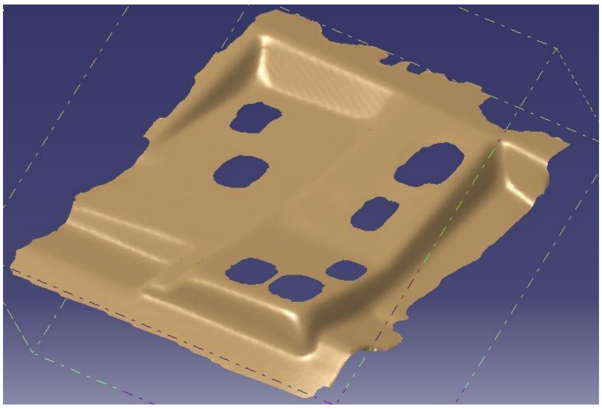


Fig. 3. Scanning result

C. Simulation Process

Before doing the simulation, the blank holder force (Fbh) need to be estimated as it is needed for an input to the simulation software. The blank holder force is determined experimentally by S. Thiruvarudchelvan et al. [7], which is 34% of forming force. The friction coefficient and model clearance as suggested by Wu et al. [1] were not included in this calculation.

The forming force can be calculated using (1) as suggested by Gharib et al. [3] and Candra et al. [8];

$$F_p = P_l \;.\; t\,(\sigma_y)\,.\,\sin\theta \tag{1}$$

where:
F_p : Forming force
P_l : Circumference
t : Plate thickness
σ_y : Yield strength
θ : Contact angle between sheet and die profile

The circumference *Pl* was estimated from the blank sheet size shown in Fig. 4 and calculated as;

Pl = 2 x (219.45 + 205.54) = 849.98 mm

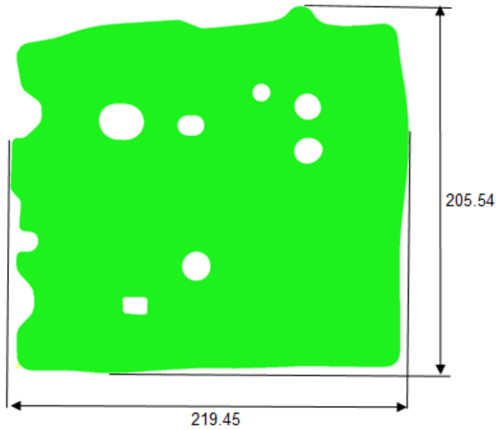


Fig. 4. Blank sheet material

Based on the existing design that we have previously reviewed, the thickness of material t is 1.6 mm. The material is SPCC 440 having yield strength σ_y of 245 MPa and an ultimate strength of 440 MPa [9].

Due to the complexity of the form shape, we assume that the forming is applied to the circumference of the part and the entire part and the contact angle θ is taken at the largest one. Hence, the forming force F_p was calculated using the area shown in Fig. 5 and the result is 322.91 kN.

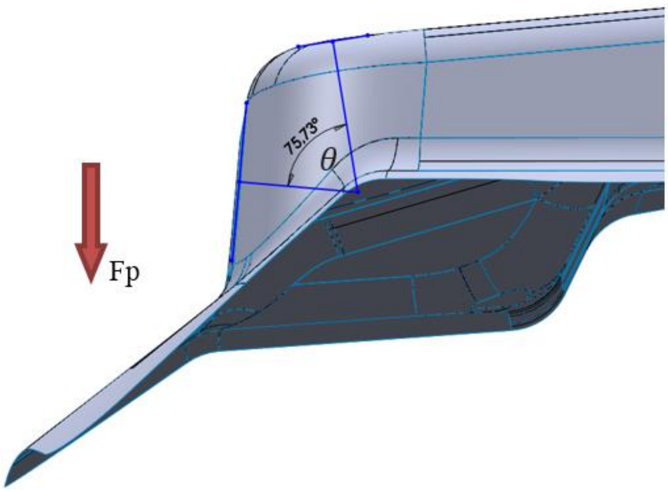


Fig. 5. Forming force 1

Thus, the blank holder force (Fbh) is calculated based on 34% of Forming force, which is 109.7 kN.

III. RESULT AND DISCUSSION

A. 3D Scanning Result

The scanning was performed to examine the deviation between the scanned data and reference data, which is an original 3D CAD model.

Before carrying out the deviation analysis, what needs to be done is to do an alignment between the reference part and the scanned part. To make it easier to find reference points, the scanned mesh must be converted into a surface model first.

Deviation analysis was done in CATIA V5 software. In the deviation analysis results (see Fig. 6), it can be seen that the largest deviation is at 3.56 mm, this part deviation comes from the scanned part of the actual production part in the company. From these data it can be said that the actual part geometry (blue) and the original drawing (yellow) are different.

The largest deviation occurs particularly on slopes (white circles) which are supposed to be a result of springback. The second largest deviation are on corners (red circles), where the actual part has larger corner radius, which are supposed to be a modification from original design to overcome crack or wrinkle during the trial.

- *Thickness Strain*
- *Springback*

The report summary of the simulation on original model issued by the software after completion of the simulation can be seen in the Table I.

The results of the simulation show that the design of this part has a high tendency to wrinkle. This is also shown in the Forming Limit Diagram (Fig, 8a) where there is a large area of strong wrinkle tendency (blue color) and small area of safety zone (green color). Therefore, it is necessary to modify the model that will be the reference for the dies.

TABLE I. SIMULATION REPORT SUMMARY

Summary		
Safety (Safe/Marginal/Fail)	Strong Wrinkle Tendency	
Minimum Thickness Strain	-14.428	Eng. (%)
Friction Coefficient	0.15	
Tipping Vector	0.000, 0.000, 1.000	

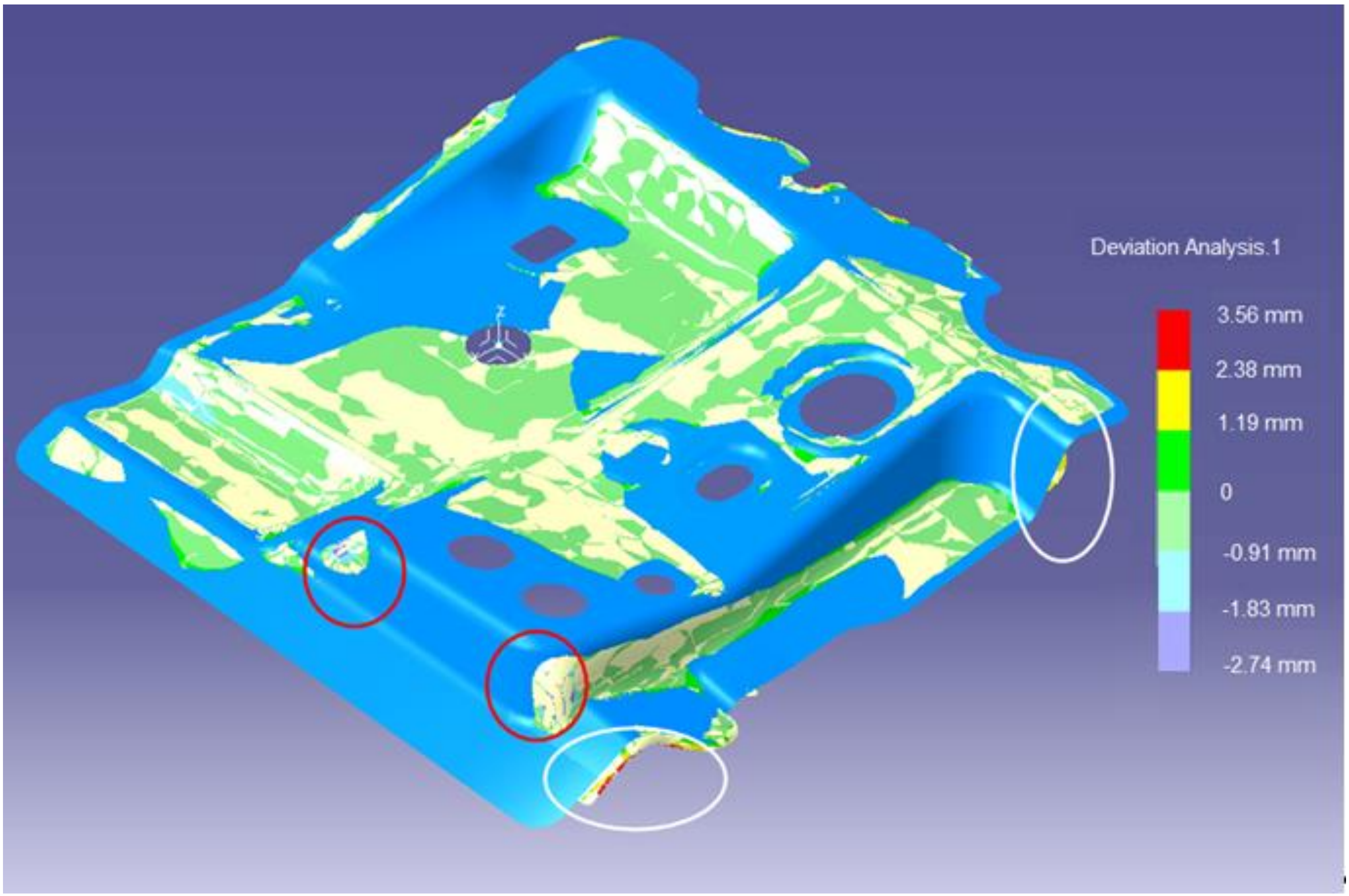


Fig. 6. Deviation analysis result

B. Forming Simulation Result

The forming analysis simulation on this part was performed in the following sections [10]:

- *Forming limit diagram*
- *Safety Zone*

C. Part Design Modification

Considering the fact that the final stamped part produced by the company has been modified from its original design as it is illustrated in Fig.6, therefore the part for simulation will be modified based on the finding that a major modification will be performed on essential corner radius.

Fig. 7 exhibit a comparison between original and modified design parts, they are overlaid one to another. The different between original design and modified parts are shown in blue color.

Another important change in the second simulation was also in blank holder force (Fbh). To reduce wrinkle and springback, the blank holder force was increased from 34% to 40% of Punch force, so now Fbh is 129.2 kN.

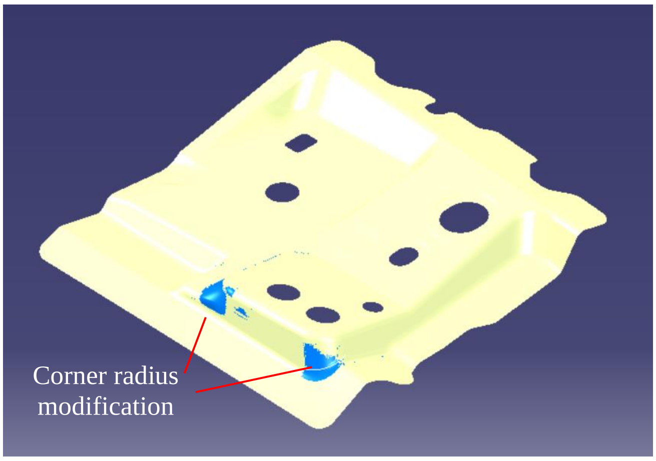


Fig. 7. Modified part design, the modified areas are in blue color

D. *Forming Limit Diagram*

Forming limit diagram is one of the most important measure in analyzing the result of stamping simulation. The Forming Limit Diagram of the original design part (Fig. 8a) shows a large portion of *Strong Wrinkle Tendency*, while the modified part (Fig. 8b) was dominated by *Safe* zone (green color) and smaller areas of wrinkle tendency (blue color). There is also a very small zone of excessive thinning (purple color) which to some extent can be ignored.

E. *Safety Zone*

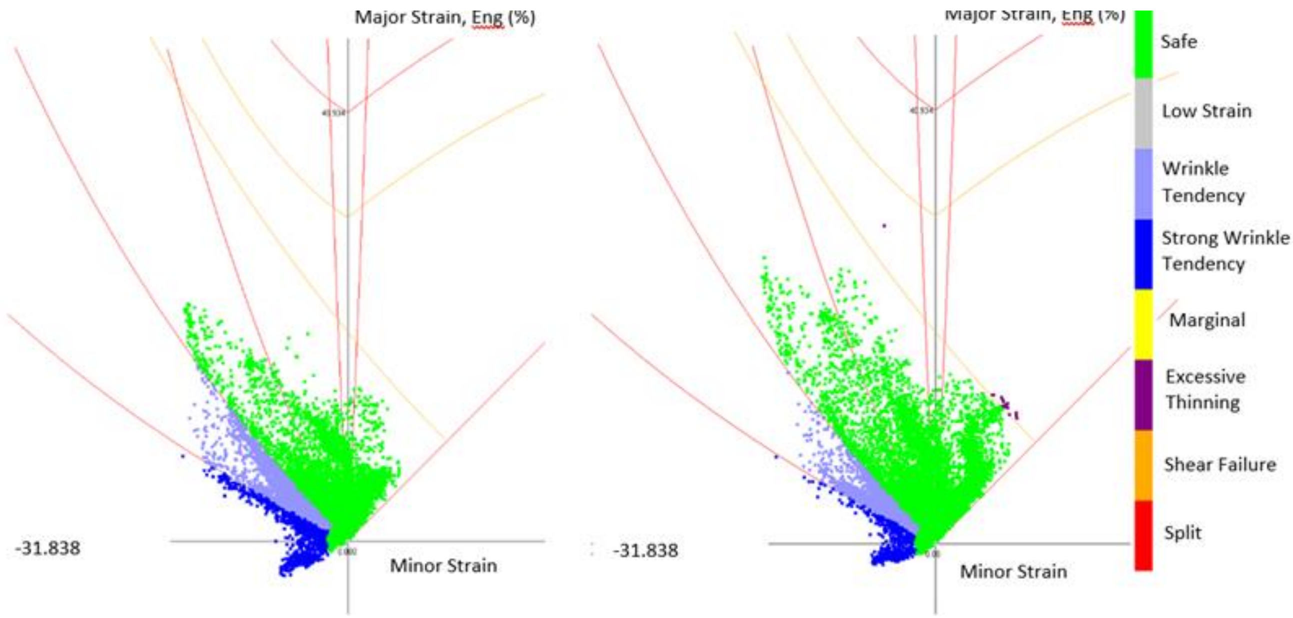
In accordance with forming limit diagram, the safety zone plots confirm the forming limit diagram result. The safety zone of original design part is represented in Fig. 9a and modified part is shown in Fig. 9b. The modified part shows a smaller area of *Strong Wrinkle Tendency* zones (blue color) compared to the original design part.

F. *Thickness Strain*

Due to the occurrence of stress on the material and flow of material during forming process, resulting in thinning or thickening of the material. It can be seen from the rendering in Fig. 10, that the thickness of the material can be differentiate from the color, with green the thickness of the material is normal, while the reddish orange color experiences an extreme reduction in the thickness of the material.

The minimum thickness strain in the original design part is -14.4% while in modified design part is -19.2%, and therefore the minimum thickness of the stamped part is 1.37 mm and 1.30 mm respectively.

To check the thinning of certain zones of the part, a measurement was carried out on the section cut of a final stamped part as it is exhibited in Fig. 11.



(a) (b)

Fig. 8. Forming limit diagram of (a) original design and (b) modified part design

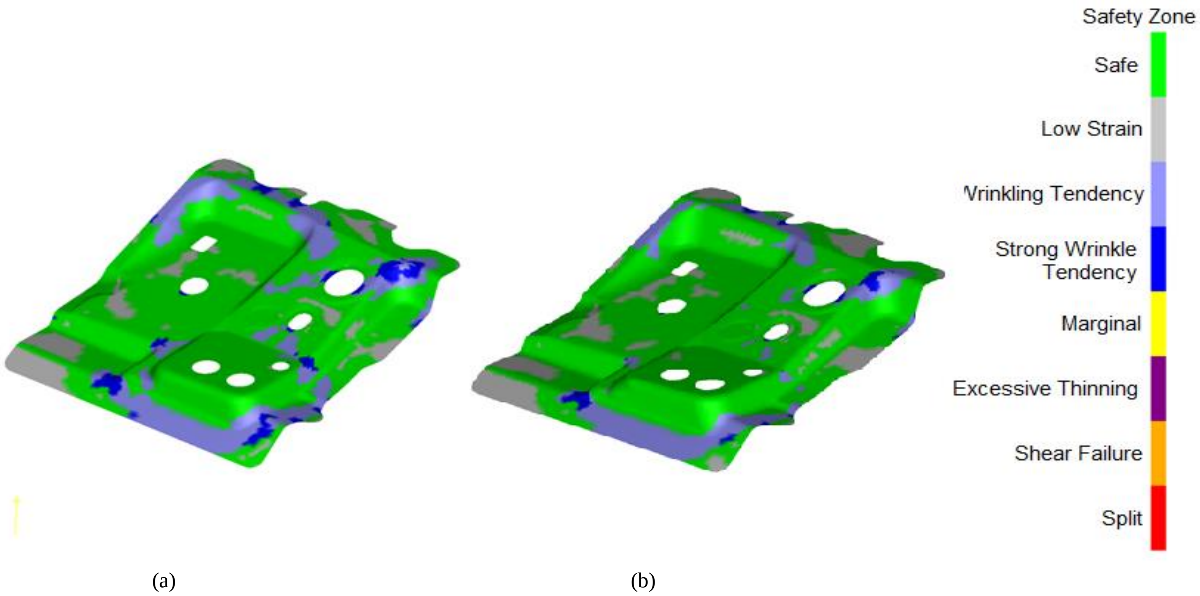


Fig. 9. Safety zone simulation results of (a) original design and (b) modified part design

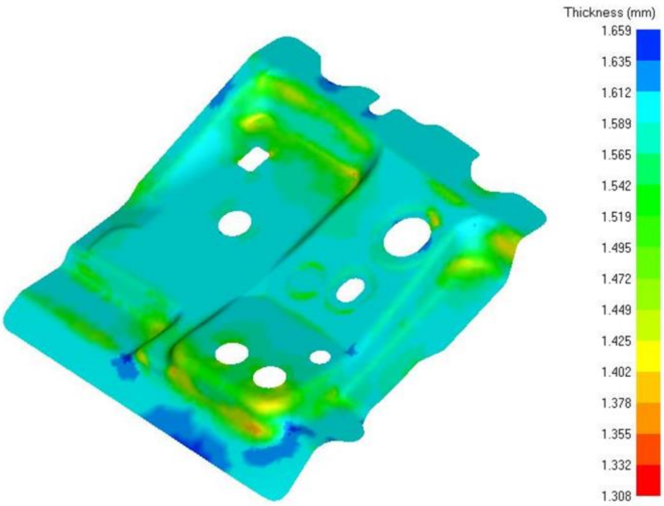


Fig. 10. Thickness strain simulation result

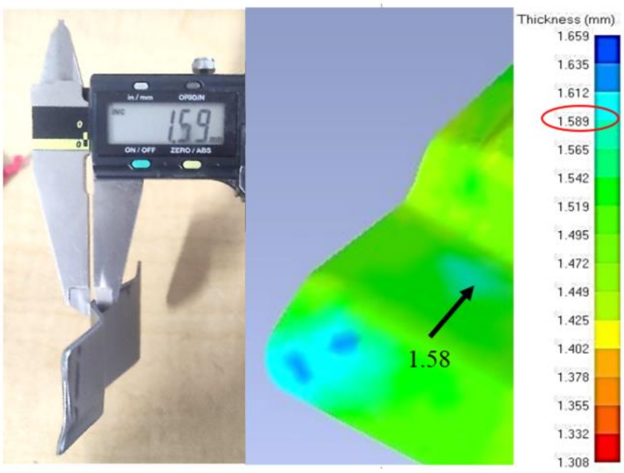


Fig. 11. Comparing thickness of actual part and simulation result

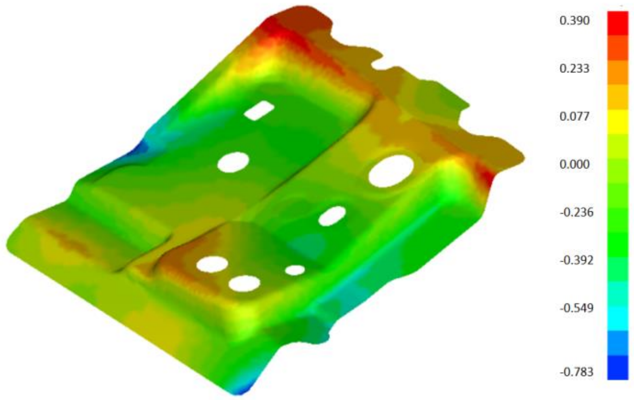
The actual part thickness was measured and compared with the simulation result and the average deviation of both values is 3.85%, as shown in Table II.

TABLE II. COMPARISON OF CHANGES IN THICKNESS OF SIMULATION RESULTS WITH ACTUAL PART THICKNESS

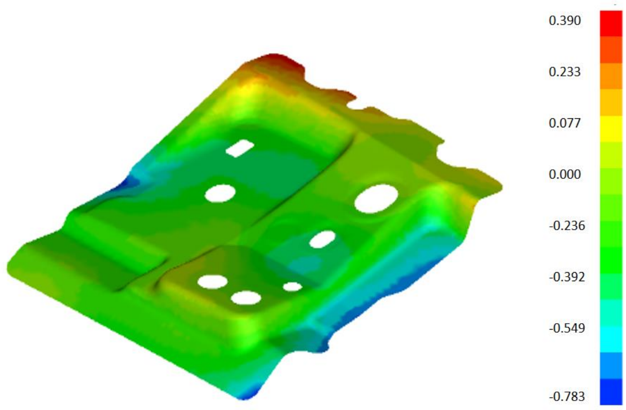
Area no.	Measure-ment (mm)	Simula-tion (mm)	Deviation (mm)	Deviation from initial thickness
1	1.61	1.51	0.10	6.25 %
2	1.59	1.58	0.01	0.63 %
3	1.53	1.40	0.13	8.13 %
4	1.50	1.49	0.01	0.63 %
5	1.59	1.42	0.03	1.88 %
6	1.45	1.37	0.08	5 %
7	1.44	1.37	0.07	4.38 %
Average deviation			0.06	3.85 %

G. *Springback*

This springback process is a reverse force caused by the influence of the elasticity of the plate material undergoing the formation process [11, 12, 13]. The magnitude of the reverse force is determined by the modulus of elasticity of the material [14, 15]. In this forming process, the springback force must be considered. The magnitude of springback deflection is exhibited in Fig. 12. The results of the springback of the original design part as it can be seen in Fig. 12a shows springback occurrence in the slope and bent areas. However, on the modified part, there is much less springback area.



(a)



(b)

Fig. 12. Springback simulation result; (a) original model and (b) modified model

IV. CONCLUSION

After being analyzed using software, there are several conclusions that can derived from the deviation analysis and simulation results. The scan data of the actual stamped part shows that the part geometry is deviated from the original CAD model. It indicates that there is already one or more modification done on stamping dies to obtained the required final part geometry. The final geometry of dies were obtained after several trials which takes three to five days.

The simulation on original CAD model using blank holder force of 109.7 kN shows that there is a strong wrinkle tendency with minimum thickness strain of -14.4% and therefore another simulation is needed on a modified model. The modification of CAD model was done refering to the scan data of actual stamped part. The modified part was simulated with blank holder force of 129.2 kN to prevent strong wrinkle tendency and reduce springback. The simulation shows good result indicated by better Forming Limit Diagram, Safety Zone, and Springback, despite of larger minimum thickness strain at -19.2%.

By doing simulation, the trial and modification of the model geometry is carried out on computer program, hence it is faster and does not need raw material. In short, the stamping die design can be developed faster, lower cost and less resources, if employ a simulation before manufacturing a new dies.

It is recommended that the current trial method in the company to consider taking advantage of currently available software and technology. To make it easier and faster to analyze and design new dies.

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