Research Article

Development of a Common Single-Die Exchange Technique for a Common Die Design in a Forging Process of a Thick Sheet

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Abstract

To minimize the production time is a key success leading to lower the entire production cost and reduce the time for a product to a market. One of the time-waste according to the lean manufacturing concept is the installation of forming dies to a press. Many methodologies are being developed to solve this problem, such as a Single Minute Exchange Die System (SMED) which considers only the technique to minimize the installation of forming dies to almost 25–30 percent, but it does not consider the minimization of the forming process or sequence. Most of the time, the automotive industries reduce the time to install the die problem by standardizing some of the die components. These parts are centralized the function for different car models. However, this technique cannot reduce the time in development of the forming processes/dies, but the number of the forming dies still remains unchanged. Therefore, in this research, Common Single-Die Exchange Technique (C-SDET) integrated with Finite Element Modeling was proposed to develop generalized common dies by utilizing the same part configurations/shapes but difference in dimensions at some areas. This technique was applied and validated with different pulley models. The results show that almost 60 percent of the forming dies can be reduced.

Keywords: Metal forming, Forging process, Common Single-Die Exchange Technique (C-SDET), Finite element modeling

1 Introduction

In the competitive manufacturing, companies need to produce products supporting their customers' demand on time. Not only the delivering on time, but the quality and cost of products also essential. Nowadays, many companies try to improve their processes by increasing the capacity with lowering the cost. However, some of bottlenecks which obstruct their objectives are the setup time during the process. This challenges engineers to reduce them as much as possible. In 1969, an engineer at Toyota Motor Company named Shigeo Shingo proposed the effective method to reduce the setup time or changeover time, especially for the forming dies [1]. This method is called Quick Changeover Dies System or Single Minute Exchange of Dies (SMED). The main idea of this method was to convert the internal setup operation which was done during the down time to be the external setup which was conducting at the run time [2].

Changeover Time (COT) is defined as a period between the last good product from previous production orders leaving the machine and the first good product coming out from the following production orders [3], [4]. Many techniques were proposed by Shingo, such as standardization of the features, mechanization system, intermediate jigs and adopting parallel activities [5]. However, the changeover is referred to two

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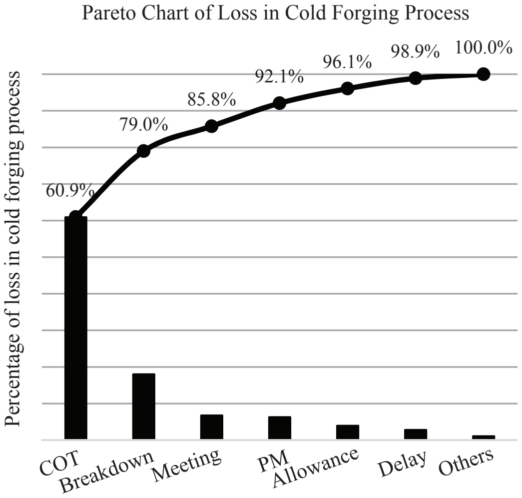


Figure 1: Pareto chart of loss in pulley cold forging process.

components which are the time during changeover and a number of changeovers. Even though, the SMED technique is able to achieve the reduction in changeover time, but the number of changeovers is neglected or remained unchanged.

In this research, the automotive suppliers face the problems of the COT in the cold forging process of pulleys for a vehicle A/C compressor. Figure 1 shows percentage details of the losses during the production of pulleys. According to Figure 1, the major loss is the COT which is considered almost 60% of the total production loss. This production is producing many models of the pulleys; about 150 models with similar shape.

According to the forming of the pulley, the overall forming process is divided to three steps for making a near net shape part. The initial raw material is the circular thick sheet with the center hole. First, the circular blank is drawn to be a cup. Then, the bottom of the cup is upset at the second forming and sent to machining process to remove excessive materials at the top tip. They are formed again at the third forming step to achieve the net-shape dimension. Figure 2 shows the forming sequence of the pulley.

In this research, the Common Single-Die Exchange Technique or C-SDET is proposed to standardize the forming tools in order to reduce a number of changeovers in the pulley cold forging process. This technique composes of two methodologies which are the classification of the product group based on the product dimensions and the determination of the common tooling design by using FEM. The technique was implemented to six models of pulleys which produced by two different thicknesses of the blanks. The first forming step tooling which composed of four main components, namely punch, mandrel, body die, and knock out, as seen in Figure 3, was targeted for reduction of a number of toolings.

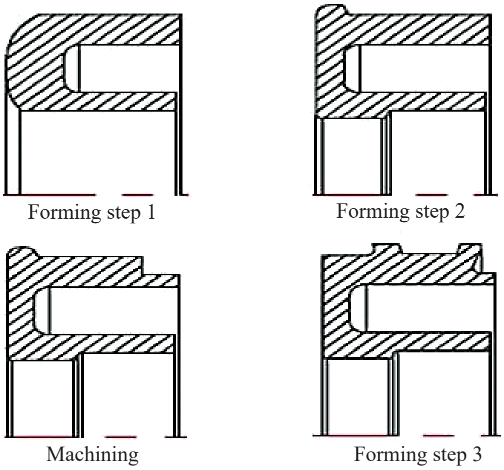


Figure 2: Forming shape geometries in each forming step.

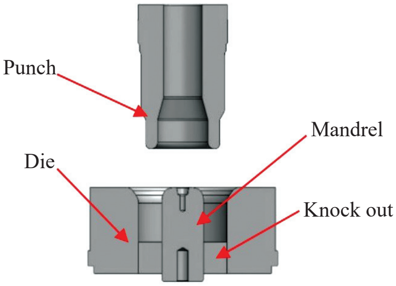


Figure 3: Illustration of the first forming step tooling components.

2 Methodology

2.1 *Products grouping (classification of the product group)*

The technique to standardize the forming tool is composed of two main steps. The first is grouping of

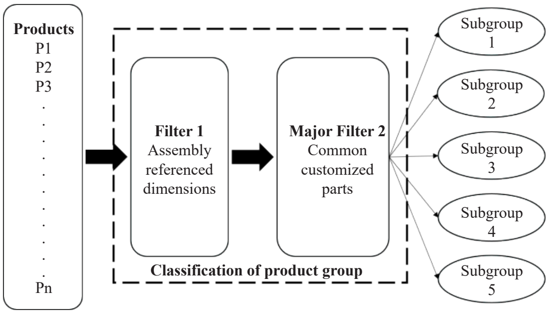


Figure 4: Flow chart of product grouping.

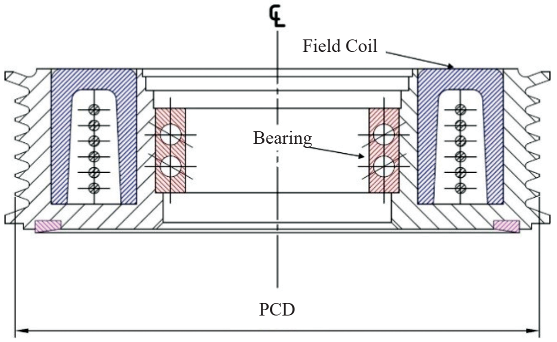


Figure 5: Schematic of assembly pulley with the standard parts and the common customize dimensions.

products or classification of the product group. All the product models will be classified by two filters which are the assembly referenced dimensions and the common customized dimensions, as seen in Figure 4. The outcome of this grouping is the product in each subgroup which shares the same assembly referenced and common functional dimensions.

In case of the pulley, it is assembled to other standard components, such as field coils, bearings, and facing plate, as seen in Figure 5. However, the field coil is only part that has many different sizes depending on the required magnetic force. Furthermore, the second filter is the Pitch Circle Diameter (PCD) which is the functional requirement of the pulley. The different sizes of PCD are designed based upon the engine speed to balance the rotational speed of the automotive engine and the A/C compressor.

2.2 *Determination of the common tooling*

The procedure for the determination of the common tooling is depicted as seen in Figure 6. Firstly, each subgroup obtained from the first classification is then designed for determining the common tooling which can be used to produce all the products within the subgroup. All the products would be firstly designed for the forged part dimensions. In the common practice, the designed forging product can be easily done by offsetting the contour of the finished shape, as seen in Figure 7, to facilitate the forming and machining tolerance which will be taken off to acquire the finished product dimension. After that, the calculation of the forming volume is done by using CAD software.

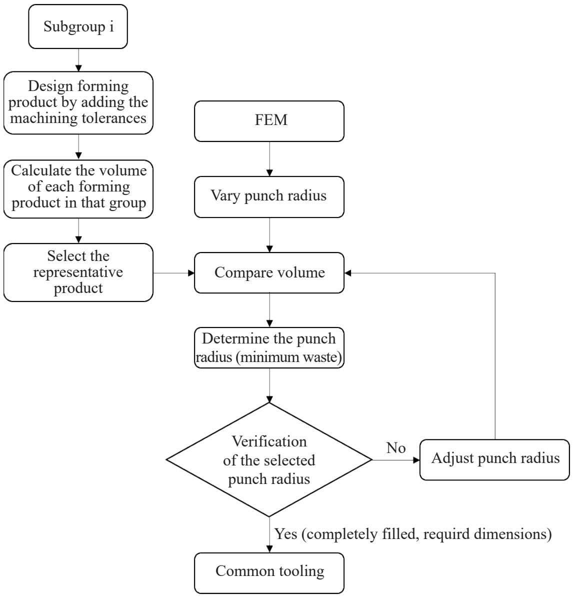


Figure 6: Flow chart of the determination of the common tooling.

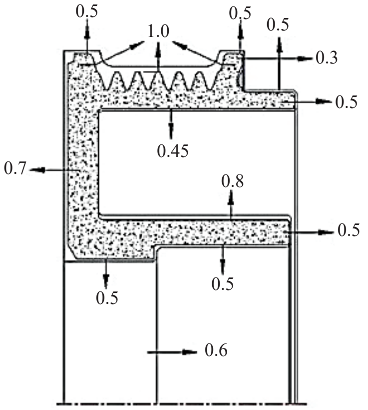


Figure 7: Contour offset criteria for forging part design.

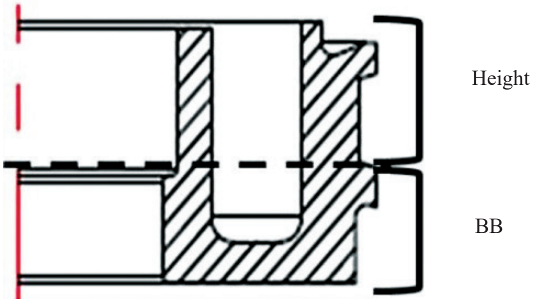


Figure 8: Height and BB of pulley.

Then, to select the representative product, two different zones which are the BB and the Height of the pulley were evaluated, as seen in Figure 8. According to this particular product, the height of the product was very difficult to control material flow when comparing with that at the BB's zone.

Figure 9 demonstrates the material flow behavior at the different zones of the pulley. When the punch travels down, it will bend the workpiece first, as seen in Figure 9(b). When the punch pushes forward, it will try to ironing the workpiece at the punch wall, as seen in Figure 9(c). At this stage, the high reduction wall thickness will happen to form the required height of the pulley. As seen in this stage, the severe deformation will occur to control the required height as well as wall thickness. After that as seen in Figure 9(d), once the height was formed to required dimension, at the bottom of the punch, the workpiece will be upset until reaching the bottom of the die. The difficult to control dimension of this part would be the height as well as the thickness. Therefore, in this study, the controlled volume at the height area will be critical for this forming.

The FEM was performed to simulate the deformation behavior and determined the required volume of the first preform that was able to make the perfect representative product. Due to the limitation of this process, the minimum of tooling modification is required. As a result, the only punch was modified by adjusting the radii, as seen in Figure 10. Thus, it is varied in FEM to determine the effect on the volume variation and the material flow.

For simplifying the simulation, FEM is set up as an axisymmetric with 3,000 elements at the blank. Blank material is low carbon steel (AISI1010). The chemical composition is shown in Table 1. The friction coefficient (m) is assumed to be constant of 0.1. [6]

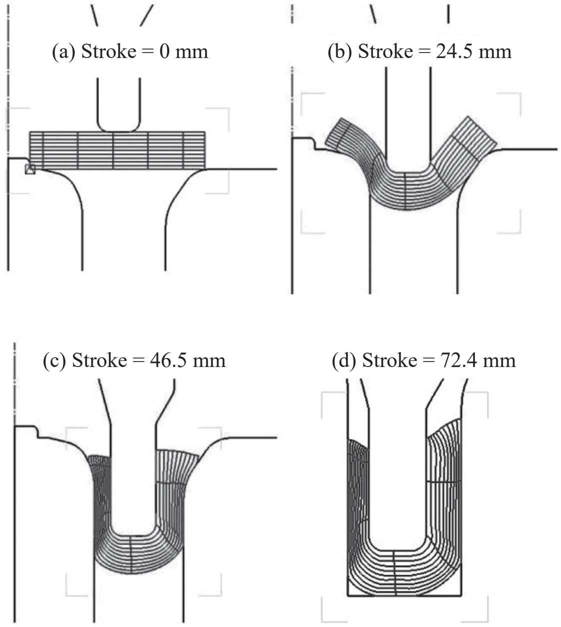


Figure 9: Deformation behavior of the 1st forming step (a) initial stroke, (b) bending, (c) ironing, and (d) upsetting.

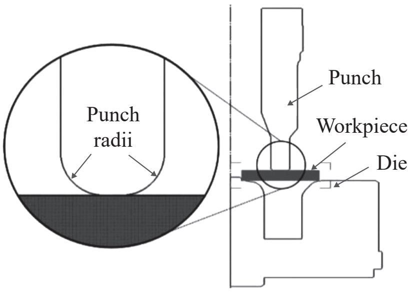


Figure 10: FEM setup of the first forming step.

Table 1: Chemical compositions of AISI 1010 [7]

AISI No.	C	Mn	P (max)	S (max)
1010	0.08–0.13	0.25–0.40	0.04	0.05

Then, the volume obtained from the FEM results and the representative product was compared to determine the point in which the excessive volume of considered zones were almost equal. That point was used for the punch radii for the common tooling. To verify the punch radii used whether it can cover all the ranges of the pulley products, the second forming step performed to evaluate any possible defects, such as underfilled and folding of the products.

3 Results and Discussion

3.1 *Classification of the product group*

The product group of pulleys were classified by this two dimensions which were the filed coil size and the PCD of pulley. As a result, the classified subgroup is shown in Table 2.

Table 2: Product subgroup of pulleys

Field Coil Size	**PCD, mm**			
	100	**105**	**110**	**115**
A	G11	G12	G13	G14
B	G21	G22	G23	G24
C	G31	G32	G33	G34
D	G41	G42	G43	G44

Then, a product subgroup was chosen to the next step. The G44 was selected as an example in this research for a subgroup to determine the common tooling.

The reason to select this subgroup was due to the high production volume.

The G44 composes of six pulleys models which are produced with two different blank sizes. The first three models are formed by the 12.25 mm of blank thickness and the others three models are formed by the 13.50 mm of blank thickness. To determine the common tooling of this subgroup, it will perform separately

For the forming tools of this subgroup, each models are produced by the individual forming dies at the first forming step so the amount of total forming tools is 24 dies.

3.2 *Determination of the common tooling*

In case of initial blank thickness of 12.25 mm, FEM was performed to investigate the deformation behavior and determine also the volume in each deformation zone. According to Figure 11, two deformed zones; the BB and Height, were considered separately.

Three products used the same initial blank with the thickness of 12.25 mm, were created and calculated their volume in the BB, the Height, and material waste by CAD software as shown in Table 3. According to Table 3, model R12C will have maximum waste among the three models.

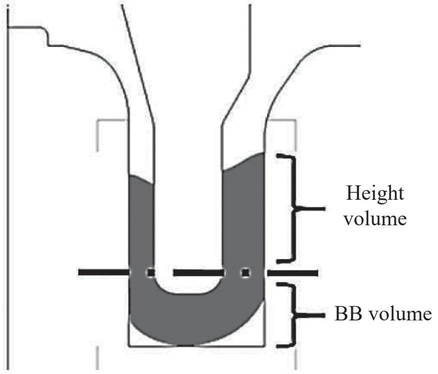


Figure 11: Height and BB of pulley in case of first forming product.

Furthermore, the P12A has the maximum volume of Height. Therefore, it was selected as the representative product for these three pulley models

Table 3: Volume calculation of the forging product of each pulley models which are produced by 12.25 mm blank thickness (unit: mm^3)

Model	**BB Volume**	**Height Volume**	**Waste**	**Total Volume**
P12A	84031	90138.7	19455.3	193625
Q12B	91465.34	84366.2	17793.4	
R12C	89026.8	84337.7	20260.3	

Then, the punch radii of the first forming step was varied in the FEM to determine the volume of preform part. After that, it was compared with the representative product, as seen in Table 4.

Table 4: Compared volume of the representative product with each varied punch radii preform for 12.25 mm blank thickness (unit: mm^3)

R Punch (mm.)	**BB Volume**	**Compared in BB**	**Height Volume**	**Compared in Height**
2	81670.3	–10.71%	111954.7	32.70%
4	89831.1	–1.79%	103793.9	23.03%
6	97907.6	7.04%	95717.4	13.45%
7.5	100507	9.89%	93118	10.37%

The compared volume between varied punch radii and the representative product was plotted and fitted as the linear relation, as seen in Figure 12. It shows that the intersection point of two fitted lines is located at the 5.14 mm of punch radii. At this point,

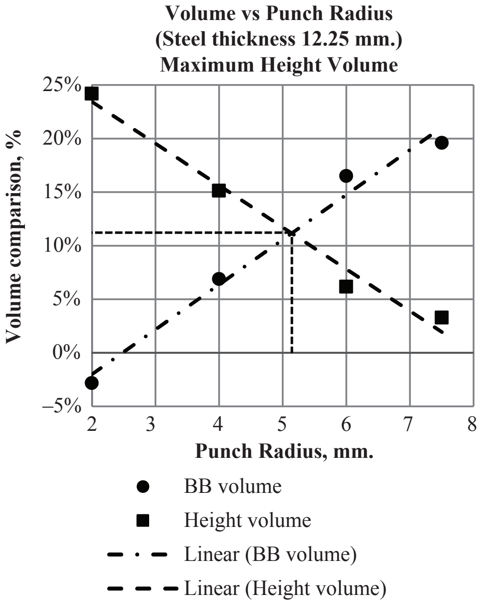


Figure 12: Linear fitted to determine the optimum punch radii in case of 12.25 mm blank thickness.

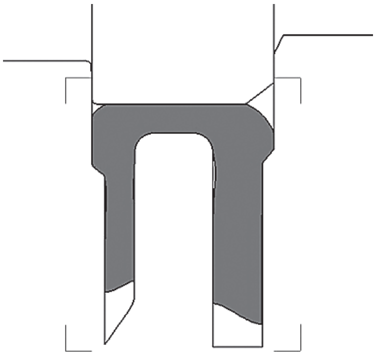


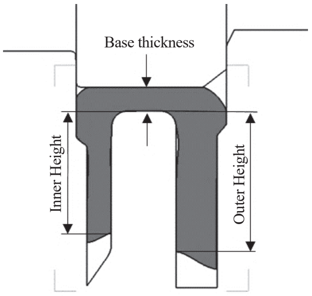
Figure 13: Verification by performing FEM in the second forming step (12.25 mm of blank thickness).

the excessive volume between the BB and Height is equal which is approximately 10%. Furthermore, this intersection point provides the minimum waste to the BB and Height. Therefore, the punch radii of 5.14 mm was selected to adjust in FEM at the first forming step.

To ensure the product quality, this first step preform was checked by performing the FEM at the second forming step and the forging defects were considered.

As a result, the second forming part was completely formed without any defects, as seen in Figure 13. Moreover, three significant dimensions which are base thickness, inner height, and outer height need to be measured. These three dimensions influence directly to the product quality tabulated in Table 5. The measured dimensions are illustrated. It can be seen that the geometry of this preform achieves the requirement that covers all the dimensions of these three pulleys.

Table 5: Measuring dimensions of the second forming step preform (12.25 mm of blank thickness)

	Inner Height, mm	Outer Height, mm	Base Thickness, mm
Minimum Required	> 27.8	> 30	> 5.2
FEM Results	30.23	32.32	5.6
			

- Initial Blank thickness of 13.5 mm.

The volume of the forming product of three pulleys were calculated via CAD software and shown in Table 6.

Table 6: Volume calculation of the forging product of each pulley models which are produced by 13.5 mm blank thickness (unit: mm^3)

Model	BB Volume	Height Volume	Waste	Total Volume
X13I	98961.8	96254.9	18973.26	214190
Y13J	101902.1	74774.0	37513.78	
Z13K	97956.8	90289.5	25943.59	

According to Table 6, the representative product of these three pulleys was X13I that has the maximum Height volume. Then, the volume of this representative was compared to the preform, as seen in Table 7.

The comparison between the varied punch radii preform and the representative products is shown and plotted in Figure 14, respectively. According to Figure 14, the intersection point which provides the minimum waste is 6.77 mm. (The point where the volume between the Height and BB is almost equal.)

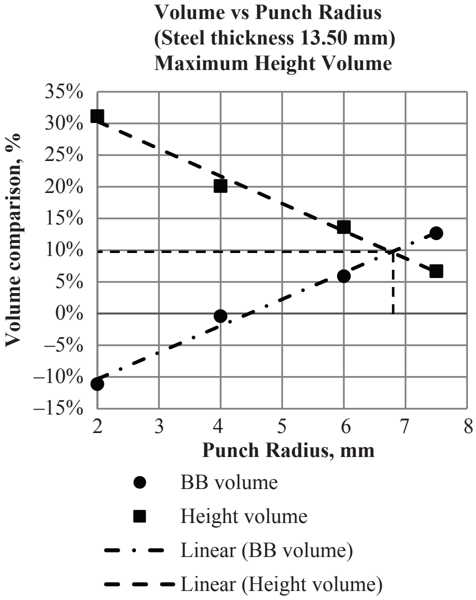


Figure 14: Linear fitted to determine the optimum punch radii in case of 13.5 mm blank thickness.

Table 7: Compared volume of the representative product with each varied punch radii preform for 13.5 mm blank thickness (unit: mm^3)

R Punch (mm)	BB Volume	Compared in BB	Height Volume	Compared in Height
2	87953.9	–11.12%	126236.1	31.15%
4	98556.4	–0.41%	115633.6	20.13%
6	104792	5.89%	109398	13.65%
7.5	111495	12.66%	102695	6.69%

According to Figure15, the verification of the 6.77 mm of punch radius is shown by the second step forming. It can be seen that the underfilled defect occurs at the BB inside. The underfilled defect is mainly caused by not enough volume at the local BB section. Therefore, the punch radii need to be modified by using the new consideration

Previously, the forming part has been divided into two parts as seen in Figure 11, but the new consideration separated the forming part into four parts; Height inside, Height outside, BB inside, and BB outside, as shown in Figure 16.

Due to the underfilling at the BB inside, the volume of the BB inside has to be investigated by different punch radius for each side, which the BB outside did not have any underfilled problem. Therefore, the outside punch radius was fixed to be 6.77 mm, and the inside punch radius was varied from 6.77 mm. to 8.43 mm. The maximum punch radius of the punch is limited by the total width of the punch. As a result, the maximum radius of the punch cannot exceed 8.43 mm.

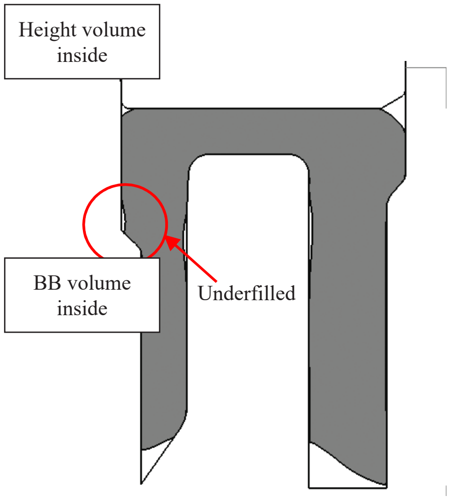


Figure 15: Verification by performing FEM in the second forming step (13.5 mm of blank thickness).

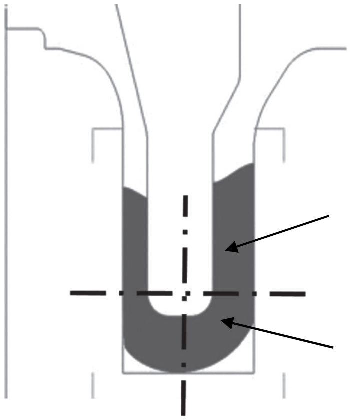


Figure 16: Verification by performing FEM in the second forming step (13.5 mm of blank thickness).

According to Figure 17, the relationship between the varied punch radii on the inner side and the changing in the BB inner and outer is shown. It can be seen that to increase the punch radius provides more volume to the BB inside as well as reduce the underfilled problem. For the BB outside, the volume does not significantly change by the variation of the punch radius at the BB inside. Therefore, to obtain the

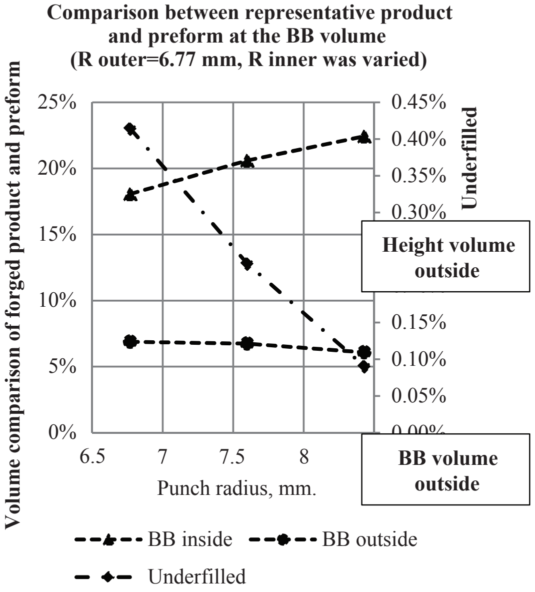


Figure 17: Verification by performing FEM in the second forming step (13.5 mm of blank thickness).

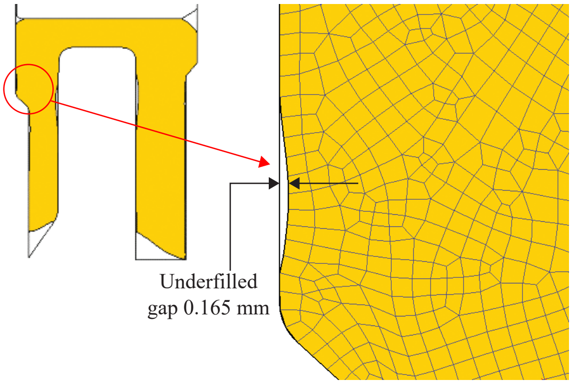


Figure 18: Verification by performing FEM in the second forming step (13.5 mm of blank thickness).

maximum volume of the BB inner, 8.43 mm of punch radius could be used.

According to Figure 18, the new modified forming part could be formed at the second forming step. However, the underfilled defect was still remained at the BB inner which is about 0.091%. Nevertheless, the depth of underfilled defect is considered to be very small which is approximately 0.165 mm, therefore, this would be acceptable within the forming and machining tolerance predefined during the design of the forged part discussed prior before.

Furthermore, according to Table 8, the measured dimensions are shown. The geometry in the critical dimensions of this preform achieve the requirement that would cover all these three pulleys.

Table 8: Measuring dimensions of the second forming step preform (13.5 mm of blank thickness)

	Inner Height, mm	Outer Height, mm	Base Thickness, mm
Minimum required	> 31	> 33	> 5.2
FEM results	32.23	35.64	5.6

4 Conclusions

This research aims to propose the C-SDET to standardize and determine the common tooling which is used to reduce a number of the forming tools in the cold forging process only in the first step forming tool. A group of pulleys which have six models with two different sizes of the initial blanks were selected as an example group for this study. Then, the following are the conclusion of this research.

- The C-SDET composes of two main methodologies which are the classification of the product group and the determination of the common tooling.
- The classification of the product group was performed based upon two filters. The first filter was the assembly reference dimensions which was the size of filed coil in case of pulleys. The second filter was the common customized dimensions based on the functional requirement of the products. In case of pulleys, the PCD was used to be a filter. However, to selection the common customized dimensions require the experienced engineers. As a result, subgroup of pulley were obtained.
- To determine the common tooling, the representative product which has the maximum Height volume was selected firstly for the subgroup. Then, the volume of the representative product and the preforms was compared to find the punch radii that can produce the minimum waste in which the excessive volume of the considered zones are equal. Later on, to ensure the product quality, the second forming step was performed to consider the forging defects and the required dimensions.
- For the initial blank of 12.25 mm, the good quality preform which has no any forging defects

was obtained and the critical dimensions were also achieved the requirement.

- For the initial blank of 13.50 mm, firstly, the obtained preform was rejected due to the undefilled defect at the BB inside. Later on, the increase of the inside punch radius can solve the underfilled defect due to the BB inside volume was increased. However, the underfilled defects was not completely eliminated but this underfilled defect was acceptable in the production because it was less than the machining tolerance.
- It should be noted that to apply this technique to determine the common tools for all products, the amount of material waste would be varied product-by-product. In other words, some products may have too much waste, but some may reduce waste. Therefore, this result must be evaluated for whether it should be beneficial of the production or not before applying this technique.

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