Dies stamping is an important manufacturing process and widely applied in the modern industrial era. It provides convenience in the production process and rapid shape modification, especially for sheet materials. However, the quality occasionally experiences dimensional change which defined as spring back (SB) and spring go (SG). This study conducted an analysis related to the factors that contribute to the defect from dies stamping. The work used galvanized sheet and processed through V-bending using thickness, punch angle and pressure as parameter. The results show the deflection angle as the main indicator related to the defect. The highest SG occurs at thickness 1 mm with a punch angle/pressure of 60°/6×10³ kg, causing the highest deflection angle of 4.45°. Oppositely, SB is observed with a maximum deflection of −2.2° when employing punch angle/pressure at 120°/9×10³ kg for material with thickness 1.2 mm. One unique result is observed for the processing material at punch angle of 90°. The phenomenon of SB and SG are observed for different parameter. For example, thickness 1 mm experiences SB when using punch pressure 3×10³ kg and 9×10³ kg, while SG is observed under working pressure 6×10³ kg. The microstructure observation shows a change in profile for the material after bending process, which is related to the mechanical deformation and when the deflection value approaches 0°, the microstructure shape profile becomes clearer which is related to plastic deformation. These results provide a reference for suitable dies stamping processing, potentially minimizing the defects and reduces the additional process that involve to repair the defect part. Thus, production quality is maintained optimally through the selection of ideal dies stamping parameters

Keywords: optimization, spring defect, dies stamping, manufacturing, punch angle, galvanized material

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ASSESSMENT THE EFFECT OF DIES STAMPING PROCESS PARAMETERS ON THE PERFORMANCE OF SPRING-BACK AND SPRING-GO DEFECTS IN GALVANIZED STEEL SHEET MATERIALS

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1. Introduction

The support of the manufacturing industry drives many important innovations to achieve the desired product quality with minimum energy consumption from the process. It is crucial considering the risk of limited supply of conventional energy source [1], especially for high power production such stamping process which has continued to be used since this method was introduced in the manufacturing process [2]. The dies stamping process is generally carried out for sheet materials, which performed for direct product formation and finalization through various processes according to specific requirement [3].

The dies stamping process is inseparable from the risk of defects. This provides specific limitations to the type of material that can be processed [4]. Product defects occur cause additional treatment after the process. The defect may occur due to the material quality and ability to be handled in the stamping process [5]. Also, potential for internal corrosion [6] of the processed product has an additional factor on the risk of defects for the final product. These conditions are also accompanied by various process parameters related to the dies stamping process [7]. The dimensional change defects associated with the spring-back (SB) and spring-go (SG) phenomena. It occurs due to the influence of the properties of the processed material and the working parameters of the stamping [8], especially for V-bending. Spring-back and spring-go defects are the most frequently occurring defects and also make things difficult for the modern automotive industry today. This is related to the formability of the sheet material so that until now there has been no definite solution to this problem.

The factors that influence it can come from the machine used, operational factors and method of transporting the material [9]. However, all of these factors tend to be neglected in the actual system [10]. Efforts to overcome the problem is complex, making process optimization approach is rarely considered in this case. The processed material that seems as the critical factor that influence the final quality of the dies stamping [11], and can be evaluated under the designed parameters to achieve the suitable stamping process. Assessment on the dies stamping processing is important which must be solved to reduce potential losses. The main problem is focused on the setting parameters which potentially influence the occurrence of defect. The assessment is ideally taken using identic material. It is based on the various dimension of the material which requires various parameter of the process. Research related to the evaluation of factor on dies stamping is highly relevant with the optimization trend in industrial processing to improve the effective production process. Hence, the given topic is suitable with the current trend on technology development as well as the need to improve the sustainable manufacturing process.

2. Literature review and problem statement

Problem related to the defect from dies stamping process has significant drawback in the manufacturing process. The paper [12] discussed in detail about the material and forming process. The study subjected the prediction of the quality of final product at the end of process while taken additional aspect on the mechanical properties of the product using modelling through machine learning. The accurate indication on mechanical properties of the dies processing can be predicted effectively. In good agreement, another study in paper [13] address explicitly the phenomenon on the spring effect for on angled structure. The forming through laser technology on the multi-layers composite demands specific and accurate parameter to maintain the final quality of the processed product. However, the use of specific models of manufacturing processes requires appropriate references related to the formation through the stamping process.

An accurate prediction model is expected to be an effective way to reduce the potential for defects related to stamping dies. The study [14] applied an advanced method through an artificial intelligence (AI) approach as one of the effective techniques for SB model prediction. There is various condition indicating linear trend and non-linear behavior for the designed parameters, making the fundamental justification is demanded on the proposed prediction model. Another approach is developed as an option to address these limitations. The study [15] aims for process analysis on the dimensional changes of the hot steel as stamping product. It is found the crucial factor that contribute on the quality is the cooling rate and cooling mechanism which causes different deflection related to the final accuracy of the process. However, the cooling mechanism and rate requires specific equipment as well as parameter which generally taken in the initial step of the processed material, making the additional aspect need to be addressed for material without experiencing heat treatment.

Different method is proposed under parametric analysis using statistical approach for the given process. The study [16] discussed the approach for specific material (plywood). The performed assessment indicated there is significant changes on the product after curing process with the maximum defect around 2.93°. In case of metal sheet material, more specific evaluation shows the impact on the microstructure level and phase of the material. For example, in paper [17] studies the issue for the material SS 316L. The finding shows there is residual stress that may affect the deformation after bending process, causing the dislocation of the primary constituent of the material, especially after processed at the punch angle of 60° and 90°. Nevertheless, considering the different constituent and composition of the material, including the perspective from its thickness must be addressed to understand the detailed phenomenon.

The consideration on the thickness of the processed material provides suitable and specific references to analyze the defect that may occur. The study [18] employed mathematical modelling to solve the potential defect problem on the pre-stressing treatment metal. The plastic stretching from the processed material is taken as the essential input for the potential of defect, making the thickness parameter is suggested as the crucial reference in dies stamping processing. The case is also relevant related to the expansion for the processed material that employs hole. As addressed here in paper [19], the friction coefficient contributes on the dimensional changes after stamping. The practical result on the stamping model is addressed in paper [20]. The crucial indicator is determined as the basis according to the stretching rate of the processed material. The dies stamping is specifically designed for brittle and hard material, making the contribution on the parameter of bending process for soft material still required in detail to achieve an accurate reference and prediction of the process.

Working parameters such as punch angle, material thickness and pressure obviously indicate the crucial factor to obtain the predicted model of defect occurrence to be more precise and considered essential for dies stamping without heat treatment. The evaluation for the factors involving in dies stamping are still necessary, particularly for low mechanical strength galvanized-metal, without processing the additional effort such heat treatment. Therefore, advance analysis relates to the working parameter and specific consideration of the processed material needs to be conducted more in depth, to provide a clear scientific reference in dies stamping process, expecting to reduce the potential defect from the process and support the development in industrial manufacturing process.

3. The aim and objectives of the study

The aim of the study is to obtain specific pattern for the quality of dies stamping process. It will support the development in manufacturing process, particularly on the dies stamping process to reduce the probability of defect regarding the produced product.

To achieve this aim, the following objectives are accomplished:

– to determine the interrelation effect between material thickness, working pressure and punch angle on the quality of dies stamping process;

– to analyze the metallography profile of the base material to observe the direct impact of the punch angle on the structural profile.

4. Materials and methods of research

This research measures the angle of the material bending resulting from the die stamping process, where the stamping dies have been designed according to the shape and capacity of the testing machine. Spring-back and spring-go usually occur due to the material shape that is difficult to process. Stamping dies parameters that can affect the formation of the material are the radius and angle of the punch/dies, material thickness and pressure. Therefore, these parameters are the main factors causing spring-back and spring-go. The most influential factor among the above factors is the shape of the punch/dies. Both the angle and radius of the punch/dies.

The spring-back and spring-go values are obtained from the resulting angle values which are then compared with the actual punch or die angle (illustrates in Fig. 1). Different punch angles usually result in varying spring-back/go values. In the world of the automotive industry, the material bending process uses large tonnage production machines. In this research, a prototype was created for the material bending process in the automotive industry and only take a few parameters from the dies stamping process, namely punch angle, material thickness, and pressure used under 10 Ton.

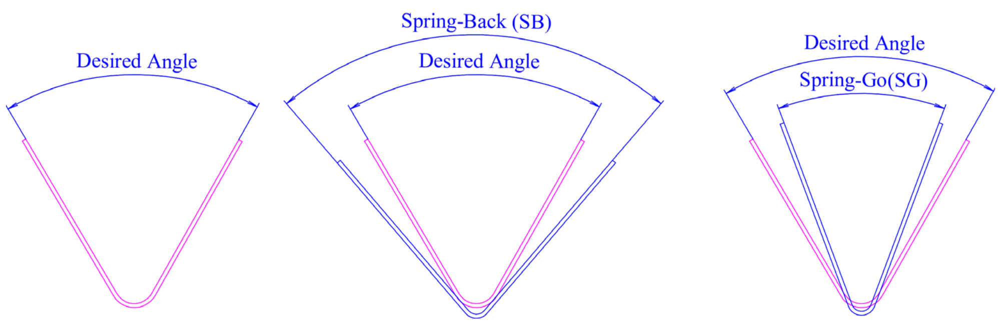

Fig. 1. Illustration of dimensional quality from stamping: *a* – desired quality; *b* – defect spring back; *c* – defect spring go

The sheet material for the assessment in this work is categorized as CRSC (Cold Rolled Steel in Coil). The maximum tensile strength of the material is 72 kgf/mm^2, with strain maximum about 37 %. The material has hardness level (scale B) 68 HRB. It shows the material able to be processed through stamping.

The schematic of the dies stamping in this work is shown in Fig. 2, *a*. The model was developed using high-precision machining to ensure the quality of the process. Also, the designed V-bending tester was made according to the ISO 7438:2020 [21]. The base material for the dies was stainless steel (SS) 400. In addition, the model was designed according to its specific parameter, particularly regarding the maximum thickness of the material and working process of the punch. The photograph of V-bending is shown in Fig. 2, *b*.

There are three critical factors for the dies stamping process [22]. The factors are considered from the material (its thickness), the bending machine (punch angle) and working pressure. This work set the punch angle at specific ratio (60°, 90° and 120°). The thickness of sheet materials were 0.8 mm, 1 mm and 1.2 mm, while the working pressure (punch pressure) were set at 3×10^3 kg, 6×10^3 kg and 9×10^3 kg. The dimension of the specimen was set at 130×50 mm for each test. The designed specimen experienced each combination of the parameter to observe the influence of the process to the deflection angle from the final product. To support the analysis, the metallography assessment was performed following the reference ASTM E3 [23]. In this scenario, one sample was taken before bending test, while the three sample were taken based on each punch angle. The pretreatment was performed by cutting the sample at specific dimension (50×35 mm), followed by polishing and etching using nitric acid (HNO_3). After that, sample was observed using light microscope (Olympus – BX53MRF) and taken to further analysis process.

5. Results of quality assessment of the product from dies stamping process

5. 1. Results of deflection angle variation under designed parameters dies stamping process

The evaluation for defect condition using punch angle 60° is presented at Fig. 3. The all value for deflection angle is observed positive which indicates the spring back (SB) condition is occurred for the all set parameters. Interestingly, the changes in parameter shows the value shifts variably. There is one clear pattern where the deflection angle decreases as the thickness of the sheet material increases. The highest deviation is observed for punch pressure 6×10^3 kg. The deflection reduces about 4° with thickness of the sheet material increased to 1.2 mm. In addition, the effect of punch force shows the ultimate value at working pressure 9×10^3 kg since the deviation of deflection angle contribute insignificantly between thickness 1 and 1.2 mm (0.1°).

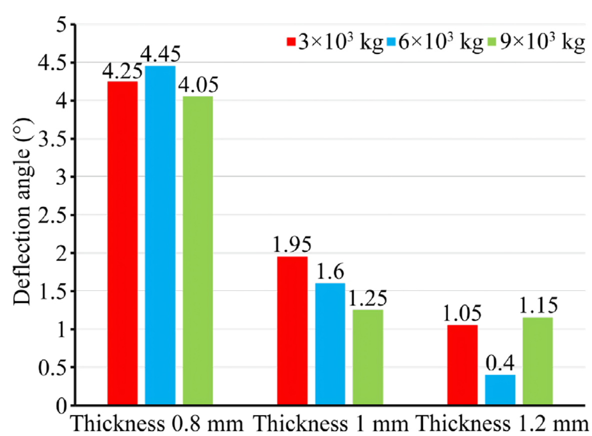

Fig. 3. The deflection angle of the tested material using punch angle 60°

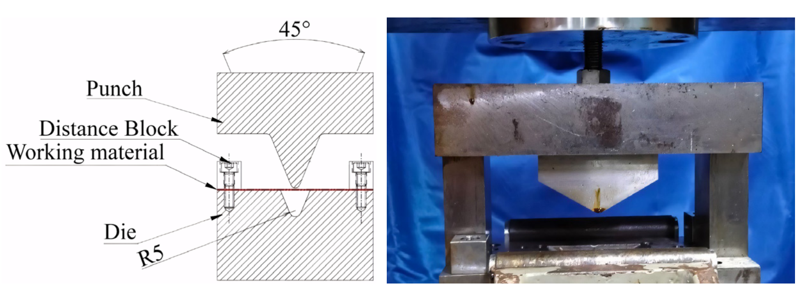

Fig. 2. Evaluation process for defect assessment: *a* – schematic and dimension of the bending tester; *b* – its photograph

Different quality is observed exceptionally at wider punch angle (90°). There are two major phenomenon that occurs simultaneously for the given parameter where the SB dan spring-go (SG) are appeared (Fig. 4). The SG is observed with negative value of deflection angle. It shows constantly for the thickness of material is only 0.8 mm, with the lowest value is achieved using punch pressure 9×10^3 kg. Oppositely, the positive deflection angle which represent SG only happen when using thickness material of 1 mm and 1.2 mm. It only achieves when the parameter is suitable, particularly for the punch pressure. A good consistency is observed for the working pressure 3×10^3 kg by considering the SB variation at this parameter only 0.15°. One more information can be drawn from this result. Increasing the forces indicates the interchange condition that turn SB into SG (and vice versa) when the thickness of sheet material elevated.

Increasing the punch angle 120° shifts the deflection angle into negative value and it is found for the designed parameters (Fig. 5). It signifies the primary chosen related with punch angle is crucial. It affects massively regarding the changes in the defect characteristic of the sheet material after bending process. Also, there is no clear pattern for the obtaining results at the given angle. Despite the tendency that the deflection angle becomes smaller with the lowest thickness (0.8 mm) ranging between –2.15–1.7°, increasing the thickness makes the value shifts greatly without clear indication on the deflection angle. The highest result is observed for punch force 9×10^3 kg with thickness 1.2 mm that reaches deflection angle of –2.2°.

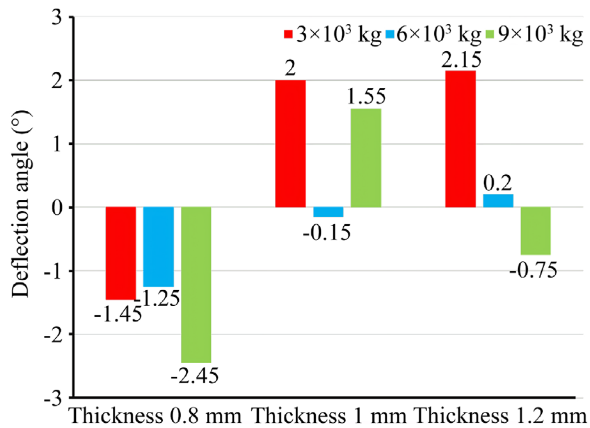

Fig. 4. The deflection angle of the tested material using punch angle 90°

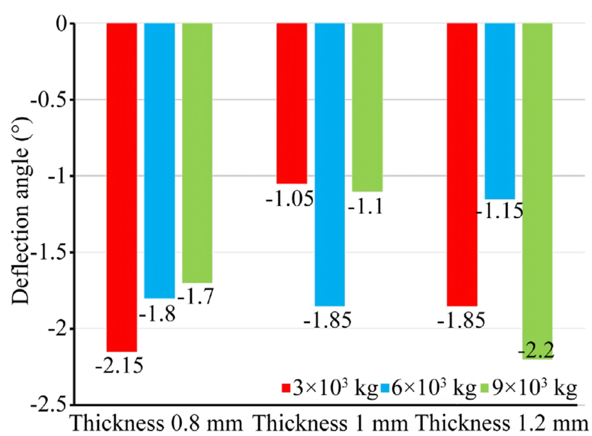

Fig. 5. The deflection angle of the tested material using punch angle 120°

The defect characteristic demonstrates each factor of the bending parameter resulting in various value related with the deflection angle. The key indicator is punch angle that provides suitable comparison regarding its final variation of the deflection angle, while the thickness and punch pressure are taken as additional factor that makes the deflection angle varies. In also, there are two identic condition that indicates the punch angle 60° causes SG while punch angle 120° resulting in SB, and it alters variably at punch angle 90°.

5. 2. Results of metallography profile of the material before and after bending test

The observation of microstructure for base material before bending is presented in Fig. 6, *a*. The galvanized is observed clearly and can be set as suitable parameter to compare the effect of bending process on the processed material. Another evaluation is taken for the sheet material after bending process with punch angle 60° (Fig. 6, *b*). It indicates there is change on the profile which becomes elongated. At this point, there is a clear impact on the effect of bending process for the sheet material.

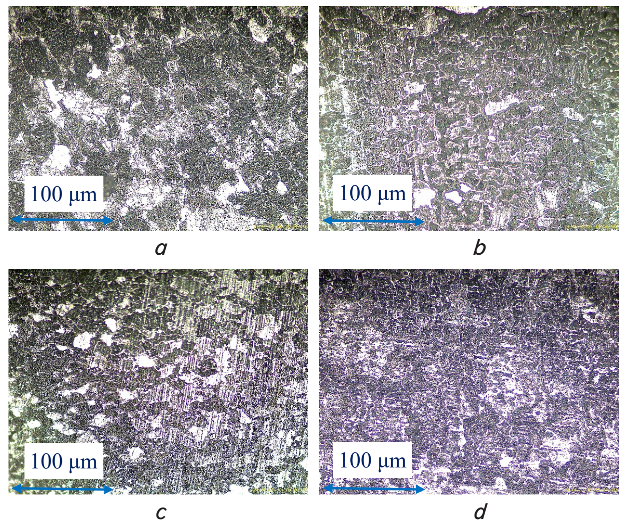

Fig. 6. Microstructure profile: *a* – base material; *b* – after bending test at 60°; *c* – after bending test at 90°; *d* – after bending test at 120°

Increasing the punch angle modifies the microstructure profile greatly. The usage of wider punch angle (90°) resulting the boundary area of the structural composite of the sheet material becomes visible (Fig. 6, *c*). However, it becomes unclear after the material processed at punch angle 120° as seen in Fig. 6, *d*. Thus, the changes in the microstructure represent a clear effect on the resulting defect of the processed material and can be referred to evaluate the interrelation effect for each bending process.

6. Discussion of the results of quality assessment of the product from dies stamping process

The analysis of factor that involved in bending process regarding the defect of spring effect reveal the quality of the process is clearly affected by the bending parameter. For instance, the main contribution on the SG condition is the positive value of deflection angle that observed completely for the chosen parameter when using the lowest punch angle (60°). As indicated in Fig. 3, the defect SG occurs entirely for the given punch pressure and thickness of sheet material. However, the value is considered decrease with the maximum value of 62.3 % if using thickness material 1 mm. Thus, adjustment on the suitable material thickness at this factor can be defined properly to ensure the effective deflection angle at desired value. Another good indicator is elevating the thickness into 1.2 mm makes the deflection angle falls to 45.8 % with the lowest value at 0.4° using punch pressure 6×10^3 kg.

Focusing for the punch pressure effect, it contributes notably once the punch angle becomes enlarged to 90° (Fig. 4). The defect is considerably low once the process is handled at pressure 6×10^3 kg, resulting the variation of the deflection between –1.25° (SB) to 0.2° (SG). The appearance of this condition takes in place when employing thicker material, causing the deflection into a positive value that leads to SG effect. The presence of suitable factor between the angle and pressure of the bending makes the probability of defect can be minimized [24]. This observation also appears when the thickness of material increases (1.2 mm), indicating the interchanges profile between SB and SG. This factor requires different approach to adjust the specific indication of the bending operation, making the punch pressure at the given angle considered as relevant factor that affects the quality of bending process.

The clear result on the increment of punch angle makes the processed material experience SB defect completely. It is appeared once the process performed at the widest angle of 120° (Fig. 5). It causes the variation on the SB defect, where the deflection starts at –1.1° to –2.2°. It affirms the initial consideration related to the increment of thickness, where the value only drops at suitable punch pressure (6×10^3 kg) with the maximum decrement of 0.7°. Rising the thickness makes the forces distributed in different mechanism that makes the deflection becomes higher at pressure 3×10^3 kg and 9×10^3 kg. It produces a higher deflection angle up to –0.8° and –1.1°.

The influence of bending process is noticed under microstructure evaluation. The basic feature of the structure for the sheet material reveals the laminated profile of galvanized sheet (Fig. 6, *a*). Processing the material at punch angle 60° develops the microstructure of the material enlarged which indicates the plastic deformation (Fig. 6, *b*). It may cause different result which potentially becomes larger once the material handled into heat treatment process 2 [25]. However, the additional process may be considered optionally while the observation of microstructure profile help to determine the suitable parameter. For example, the microstructure distribution is seen into a tighter profile after process at punch angle 90° (Fig. 6, *c*). It is also the only bending parameter that closes to the desired angle, indicating the defect can be minimized. In contrast, observation for the microstructure profile for the punch angle to 120° (Fig. 6, *d*) illustrates the sheet material unable to reach the plastic region, making the defect appear as spring-back condition.

Observation of bending parameters on the defect spring effect clearly shows the role of each factor related to changes in deflection angle. However, the values of all parameters in principle still show their own limitations related to deflection. This can be minimized by making modifications according to process temperature and also considerations on the holding time of the process for further research. In addition, this study is limited to the function of deflection angle and microstructure observation. Thus, there is a great opportunity for further evaluation related to mechanical strength factors and also specific parameters that can be adjusted based on the findings of this study.

7. Conclusions

1. The parameter that most affected the occurrence of spring-back/spring-go defects from the three parameters is the punch angle. At an angle of 120° the test object experiences spring-go, at an angle of 90° the test object experience both spring-back and spring-go, while at an angle of 60° the test object experiences spring-back. The smaller the material pressure, the easier it is for spring-back defects to occur. The greater the material pressure, the easier it is for spring-go defects to occur. At a pressure of 0.3 tons the test object experiences spring-back. While at a pressure of 0.9 tons the test object experiences spring-go. The smallest material thickness has an impact on spring-back defects, while the largest material thickness has an impact on spring-go defects. With a material thickness of 0.8 mm the test object experiences spring-back defects. While with a material thickness of 1.2 mm the test object experiences spring-go defects.

2. Based on the results of observations using a microscope, the bending/bending process of the material affects the microstructure of the material. The smaller the angle formed, the flatter the grain boundaries due to the attraction between the tensile strengths of each grain boundary.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Data will be made available on reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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