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Design and Analysis of Progressive Die for Chain Link Plate

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Abstract: ***Progressive die follows a sequence of processes in a single die at two or more stations. Design of progressive die is an essential phase in sheet metal manufacturing. Small error at any workplace causes huge manufacturing downtime due to die failure. In this analysis, current die design has low production rate when using multiple stations for sheet metalworking. Each process produced by multiple stations, which increases the loss of time. However, the choice of proper materials for sheet metal plate has become one of the vital features of progressive die design. Due to its long die life has become a requirement for lowering the cost of sheet metal mechanisms. The punch has very short life cycles. The purpose of this paper is to design a new 3D modelling of sheet metal forming die, to optimise a new chain link plate material to improve the performance of the punch component and to analyse the sheet metal punch to increase the punch lifetime cycle. The analysis was conducted by using ABAQUS/CAE to analyse the maximum and minimum stress of punch. The materials used are stainless steel, nickel plate and mild steel. The result of maximum stress obtained from ABAQUS/CAE is used in stress-lifetime prediction calculation. Based on the theory of stress-lifetime prediction, the lower the stress required to deform a material, the longer the life cycle of the punch. From this calculation, we can identify which material is the most suitable for chain link plate production.***

Keywords: ABAQUS CAE, chain link plate material, progressive die, 3D modelling, lifetime cycle.

I. INTRODUCTION

In a progressive die, the workpiece is produced in several steps. At each station, one or more die operations, such as piercing, notching, blanking, coining, shaving, drawing, and forming, are performed on the sheet metal strip. The result is a finished workpiece at every stroke of the press. Because of their competitive productivity and performance, progressive dies for producing sheet metal parts in mass production have been widely applied in various industries such as aerospace, electronics, machine tools, automobiles, and refrigeration. However, the structure of a progressive die is complex, and the design cycle is long. Other than that, the following design procedure is composed of two phases, stamping process planning and die structure design. Stamping process planning is to produce a flat pattern of a model of stamped metal, plan stamping operations and obtain strip layout. The die structure design process consists of die set selection, design of punches and insertion of assistive devices such as pilot pins, ejectors, dowel pins, standard parts, etc.

On the other hand, the finite element method (FEM) is being used in research and industry to analyse the metal forming process for manufacturing net shape product. The main advantages of the FEM are the capability to obtain detailed, accurate solutions of the mechanics of deforming bodies such as stress field, strain rate, and contact force. A computer-aided approach using FE simulations can reduce the number of prototype runs and reduce product development cost. In this study, finite element simulations were used to address the following problem in the stamping industry.

In this study, three problem statement can be compound in research. Firstly, current die design has low production rate when using multiple stations for sheet metalworking. Each process produced by multiple stations, which increases the loss of time. Each process can handle only one unit at a time, and each part must be processed through the next station. Secondly, the choice of appropriate materials for sheet metal plate is an important feature of progressive die design. As the long die life is a requirement for attaining higher efficiency and cut cost of sheet metal components. Mostly, choice of materials for progressive die components is done manually using die design guides and material manuals. Lastly, due to the drastic changes in consumer requirements, the punch has very brief life cycles. Even now, few sheet metal industries use conventional CAD/CAM setup for progressive die design and manufactures. The purpose of this paper is focusing on 3D modelling design of progressive die by using SOLIDWORK software.

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The study was started by focus 2-unit product in one stage process. After that, die structure will be simulated by using ABAQUS CAE (finite element method) software.

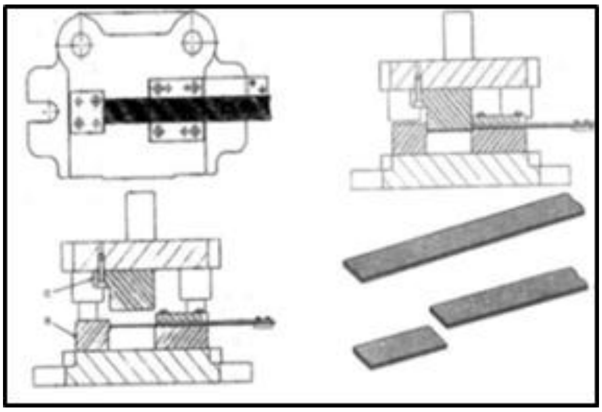
There are several steps to follow to get the best result of stress and deformation of the sample. From this process, the project will determine the chain link plate material, to obtain the highest strength for the die component and to reduce the cost of the component. Besides, three materials will be compared to get the best result of the punch. The materials are mild steel, nickel plate and stainless steel. The material was selected to compare the life cycle of punch. The formula of the calculation also will be included in this project.

II. LITERATURE REVIEW

Stamping is all operations done on sheet metal like piercing (make holes with the circular shape or other shapes in sheet metal) or blanking (same to piercing process but the cutting area is the product) or bending or embossing or drawing or extruding or curling to produce a specific product. (Suchy, 1997) In other words, stamping is the process of getting a product from sheet metals (raw material) by using a tool (die). There are many operations that can be done on sheet metal as known previously, up to variations of these operations the dies also vary in types and construction.

The essential operation of a cut off dies consists of severing strips into short lengths to produce blanks. The line of cut may be straight or curved, and holes or notches or both may be applied in previous operations.

- Cut off Dies- Cut off dies are used for producing blanks having straight, parallel sides because they are less expensive to build than other dies. In operation, see Figure (a) the material strip A is registered against stop block B. Descent of the upper die causes the cut off punch C to separate the blank from the strip. Stop block B also guides the punch while cutting occurs to prevent deflection and excessive wear on guideposts and bushings. A conventional solid stripper is employed. (Purushothaman & Technologies, 2014).
- Piercing dies- Piercing dies pierce holes in stampings. There is one principal reason for piercing holes in a separate operation instead of combining piercing with other operations which are, when a subsequent bending, forming, or drawing operation would distort the previously pierced holes. The insert in Figure (b) is shown a flanged shell requiring four holes to be pierced in the flange. If the holes were pierced before the drawing operation, they would become distorted because of the blank holder pressure applied to the flange in the drawing process. (Purushothaman & Technologies, 2014)
- **Progressive dies**- During progressive die process, the strip move in stages between stations. Diverse operations are done on it at each station excluding idle ones applied to provide room for components. A complete workpiece is removed from the strip at the final station. In the illustration in Figure (c), a pierced, trimmed, and bent part is to be produced entirely in a simple progressive die. At the first station, the strip is notched and pierced while at the second station the blank is cut off and bent. You should easily recognise all of the elements in this die block, piercing punch, trimming punch, knockout, stop block, and all the others. (DAVID A. SMITH, 1990).



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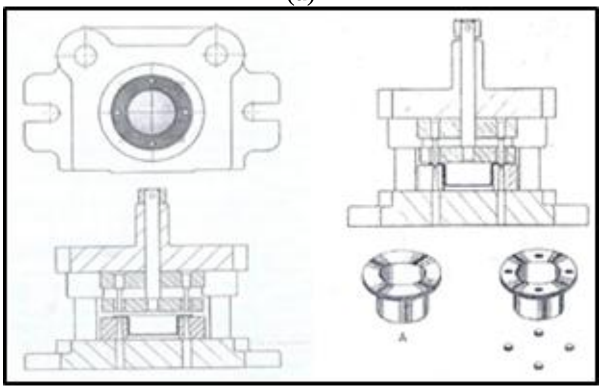

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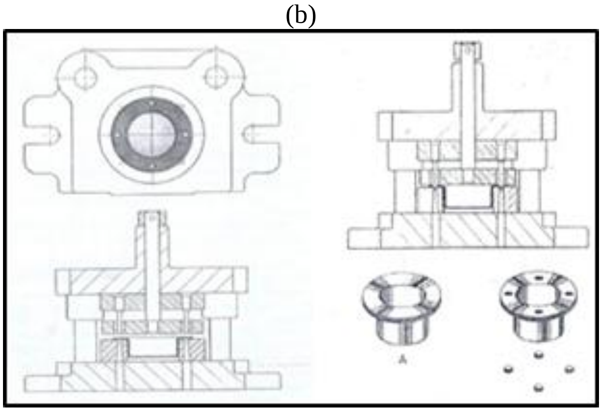

(c)

Fig. 1.Stamping die operation (a) cut of the die, (b)Piercing die, (c) Progressive die

Stripper plate, top plate, bottom plate and Guide pillars are the most essential elements of the die set, and these two plates are guided by the guide pillars. This alignment is done here for improving accuracy, part quality, die life and reduce the setup time. The lower plate supports the die, die housing, raisers, and the top plate supports the punch, punch backup plate, and guide pillar bush

- Bottom plates are the base of the lower assembly. There is die block, raiser, and guide pillars are positioned on the bottom plate. This bottom plate is used to clamp the lower assembly of press tool over the bolster plate by using the clamping devices.
- Punch- Punch is made part of the press tool. The cutting operation is carried out here. So the material required for manufacturing the punch is harder than the part material.

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The thickness of punch is depending on the punch alignment with stripper plate, compressed length of spring, and with punch travel.

- Top plate- The top plate is the base of the upper assembly. There are punch, springs, and guide pillars bush are placed upon the top plate. The tool shank, that points the whole tool in the centre with the press ram, is also fastened into the top plate.
- Guide pillar- Pillar and bushes lead the motion and partially fixed tool in the press and to confirm correct orientation amid the punches and die. The pillars are also manufactured by hardened material to resist the buckling effect.
- Stripper plate- Once the cutting process is completed, the punch pulls out from the die, but the stock strip moves away along with punch. So for the next process strip cannot be taken forward. For simplicity, one plate is secured directly above the die plate. The removal of the strip from punch is named stripper. This leads the punches and pilots in this plate to confirm position with a punch and die.

Strip layout is the process of determining the sequences of operations doing on the strip, which is first until reach to the final product (piercing blanking bending cutting). Where 100,000 pieces are to be delivered within a month is entirely different from that where the same number of parts must be produced within a week or perhaps even a day. About the number of parts to be produced, a perfect strip layout should be drawn next. It will help to evaluate the correctness of the first rough assumption, and it will also establish the exact location of blanks within the strip. Parts may be positioned horizontally, vertically, or at an angle. They may be placed beside each other or intertwined, or we can produce two or three products in every stroke. The usages of computer software's (for example, solid works) will simplify this layout.

The Finite element analysis (FEA) is inevitably required for accurate metal forming study. Since 1970, the Finite element concepts have been established to provide valuable data about the real procedures in industries. FEA is used in engineering and is commonly recognized as the modelling tool. Therefore, there is a high amount of software packages accessible for use in variety of engineering problems. (Nottingham & User, 2002). The FEA of the forming procedure provides data related to load, deformed shape, strain and stress distribution.

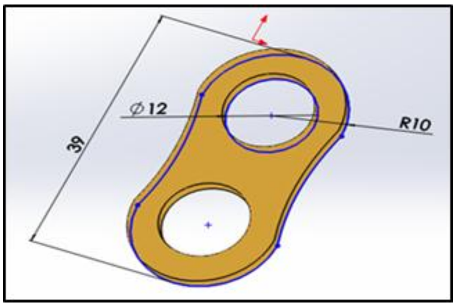
To evaluate the dies prediction of life, physics-oriented models are practiced. The service lifetime of dies is restricted by numerous factors, namely: dimensional error produced by macro-wear, overstress triggered by stress concentration and the fracture instigated by fatigue (Y. Kim & Choi, 2009). The life of the die can be predicted appropriately by modelling the wear and fatigue information. Lately, numerical simulation is extensively implemented in several metal forming applications for the approximation of tool life. (Behrens, 2008) also, (Behrens & Schaefer, 2005) used FEA to compute tool wear using hardness changes. (D. H. Kim, Lee, Kim, & Kim, 2005) Additionally, (Y. Kim & Choi, 2009) described two approaches for approximating die service life compared to plastic deformation and wear. To lower the maintainance cost and to enhance life-cycle value of elements, it is required to swiftly evaluate the remaining life of used parts as the operation procedure can be conducted continuously.

III. METHODOLOGY

This subtopic is discussing the software that uses for design strip layout method of the chain link plate. There are also discussed, about 3D modelling design of progressive die by using 3DQuickpress software. The project is used the SOLIDWORKS program for design the strip layout because SOLIDWORK 3D enables product designers and easy to incorporate design changes throughout the development process, right up to final manufacturing.

A. Strip layout design

Strip layout is the main parts of this project to producing progressive die. There are a few processes related to each other to present the final output. Creating a strip layout can be done with two approaches: Feature Base and Swap Part procedures. Both of these methods need an extended part or multiple stretched parts to start the strip design. The strip arrangement file is a part file which contains the data about the unfolded part. The strip design part signifies the metal forming processes. The result is an correct depiction of the actions of every station that occurs during the run of the die. The initial layout of the chain link plate in Figure (a) is a first step to create a strip layout. After the initial layout was complete, the numerous types of cutting punches are created using 2D structures to characterize the strip layout operation. Figure 2 shows the operations of strip layout that manipulated in several ways, as well as operation order, activation state, and mirroring operations.



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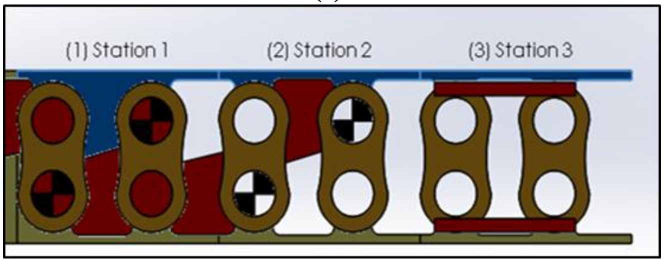

(b)

Fig. 2.Main part of progressive die
(a) The initial layout of chain link plate,
(b) Strip layout operation

B. Punch design

Punch design is the third step in the procedure of making a die design with 3DQuickPress. In this work, the process for punch design takes an available strip layout part and generates a punch design assembly.

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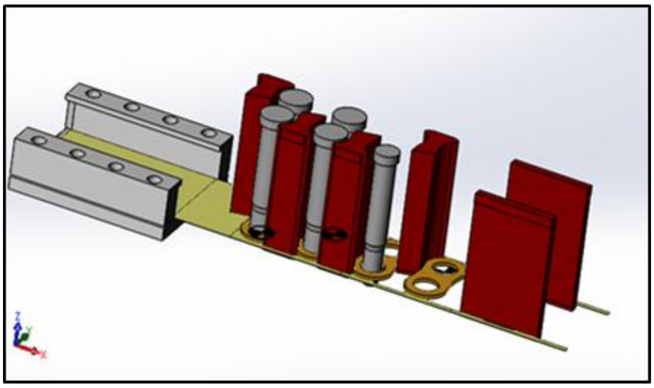
This process defines the die set limits for the tool so that the aforementioned die set is automatically formed in the subsequent design steps. In Figure 3 illustrates the process used for automatic punch design and semi-automatic punch design tools to achieve placing pilots, piecing, and notching operations. This process presented some efficient tools to move, copy, and edit components.



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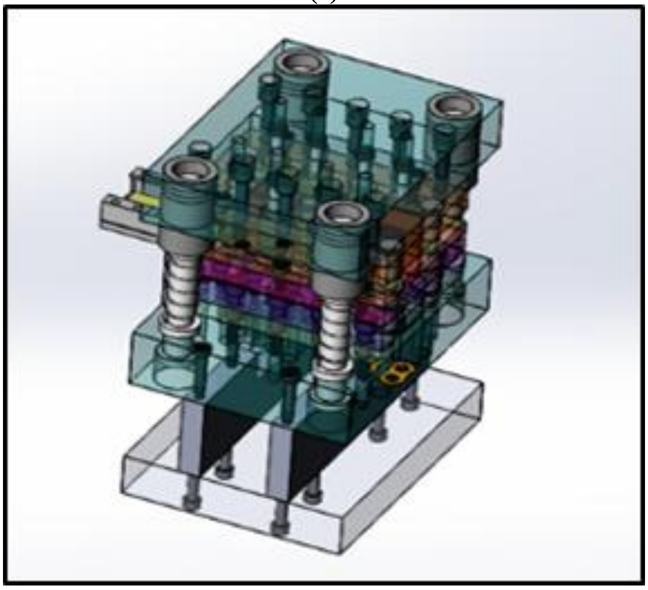


(b)

Fig. 3.Progressive die design
(a) Punch design,
(b) Full assembly design for die set of progressive die

C. Die set

After punch design, the Die set design procedure is carried out using 3DQuickPress. In the figure above is shown full assembly design for die set of the progressive die without strip layout design process. The procedure is automated to preserve standards by agreeing to modifications.

1) Bottom plate

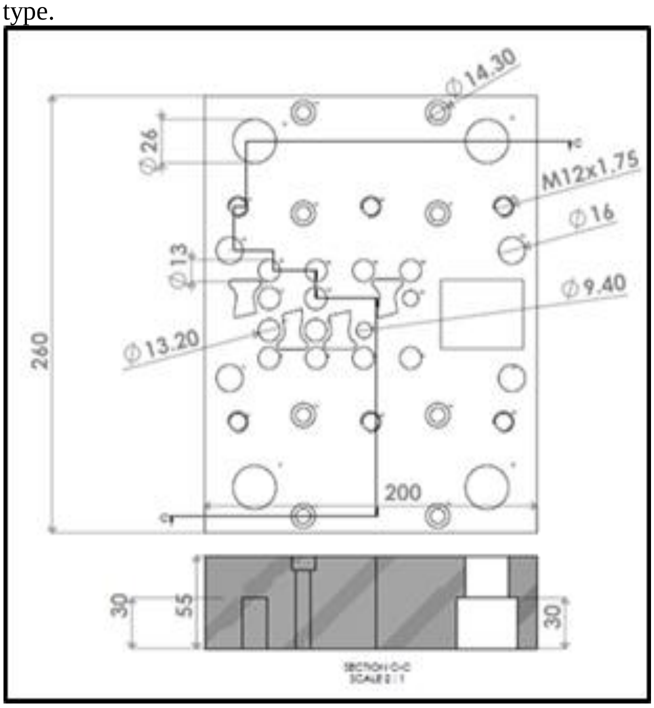
The main purpose of the bottom shoe is to provide a base for the entire die assembly. The bottom shoe is secured or fastened to the bolster plate over the press bed. There is die block, raiser, and guide pillars are mounted on the bottom plate. In Figure (a), drawing design for bottom plate has been made by using 3DQuickpress software

2) Top plate

The upper shoe or the top plate grips the upper half element of the die, fixed to the ram utilizing the shank being attached on its top surface where the centre of pressure is positioned. In Figure (b), the top plate base has been designed by using 3DQuickpress. There are punch, springs, and guide pillars bush are mounted on the top plate

3) Stripper plate

Figure 4 depicts the main objective of a stripper is to remove the stock from the punch after a piercing, nothing or pilot operation. Firstly it guides the strip if fixed to the die block surfaces. Secondly, it holds the blank under pressure before the punch descends fully if the stripper is of spring-loaded type.



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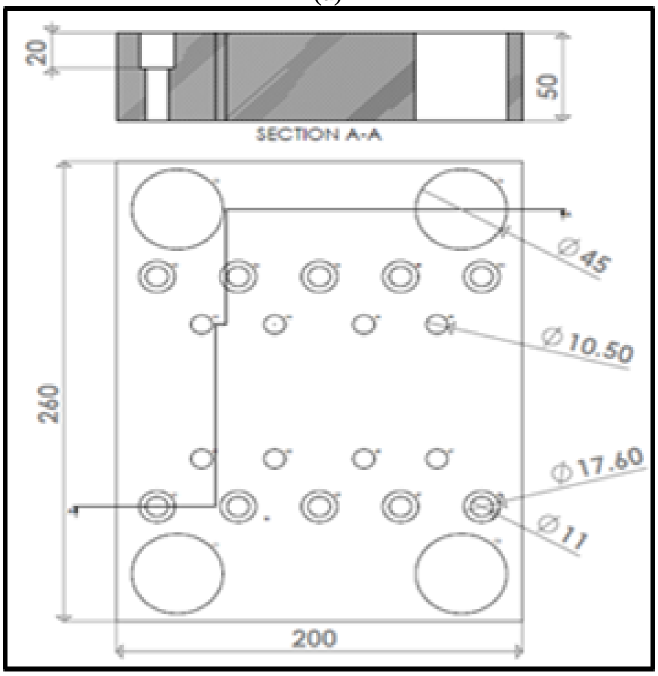

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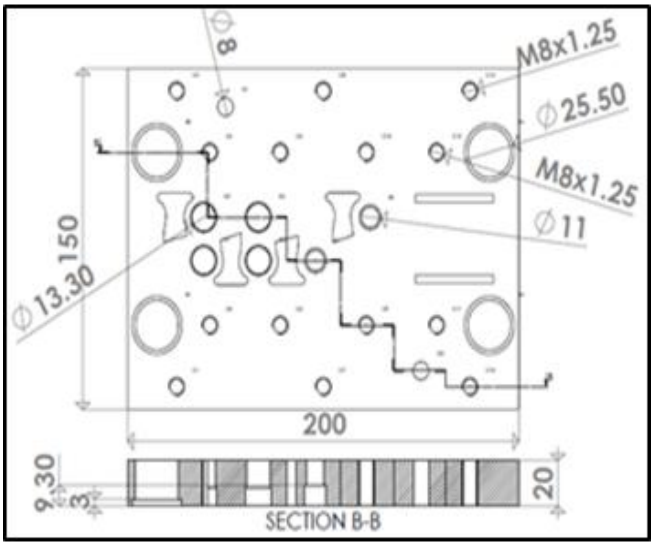

(c)

Fig. 4.Part of progressive die
(a) The bottom plate, (b) Top plate, (c) Stripper plate

D. Stamping calculation

To get an accurate calculation, stamping calculation must convert all of the values to the same unit of measurement, (inches, mm, and tons). The economic factor is also known as material utilisation. When getting into high-speed, high-strength materials and draw calculations, the tensile strength must be known to calculate the cutting force to get the total force in tons and stripping force of the punch and die. If the punch and die are kept sharp, then the total required tonnage can be reduced by multiplying by that percentage. All calculation was calculated by using formula;

Material Utilization,
Economic Factor= (AxR)/(BxV) 100% (1)
Where:

A=Blank area (〖mm〗 ^2)
R=Number of rows per strip
B=Width of strip
V=Pitch of strip

Cutting Force, F=L x T x σs (2)
Where:

F=Cutting force
L=Total length of the cutting edge (perimeter punch)
T=Material thickness
σs=Shear strength

Total Force = Cutting Force (3)

Stripping Force = 10% x Total Force

E. Finite element method

In the present work, finite element analysis of the piercing punch component process was carried out using ABAQUS 6.14.1 software package. The ABAQUS is general-purpose software which provides quality engineering tools to help all of the design and analysis needs. ABAQUS/CAE is divided into modules, where each module defines a logical aspect of the modelling process. The analysis of a process in ABAQUS consists of the following modules:

- Part module
- Property module
- Assembly module
- Step module
- Interaction module
- Load module
- Mesh module
- Job module

F. Lifetime prediction

Predicting fatigue life has been one of the most critical problems in design engineering for reliability and quality. When the component undergoes cyclic stress and strain, fatigue failure occurs which leads to permanent damage. The main components to fatigue failure are the spread of the cracks under cycling load. The crack spread life is ignored in design as the stress stages are high. In addition to computing fatigue life of punch, E-fatigue analysers are used to transform FEM stress outlines into fatigue life or safety factor contours. Just upload the FEA results value and let E-fatigue do the analysis. E-fatigue delivers analytical tools for processing FEA data and estimate the stress-life result of the life cycle. There are several steps that must be followed in the E-fatigue calculation.

- Step 1: Define the stress-life analysis (Maximum and Minimum Stress)
- Step 2: Input the material property of punch
- Step 3: Identify the modifying factors of punch
- Step 4: Define the stress concentration factor
- Step 5: Calculate and get the result of the life cycle of punch

With an E-fatigue calculator that can be made to do a simple fatigue analysis, compare results from different material, and find a stress concentration factor

IV. RESULT AND DISCUSSION

Based on table 1, shows the result from the structural analysis of punch from ABAQUS/CAE Finite Element Analysis (FEA and the value of the maximum and minimum test analysis. However, the pressure and force of impact were different between the three test materials. Since, the difference between the three materials values of stress, translational displacement and reaction force had a big gap.

Table- I: The result from the structural analysis of punch from ABAQUS/CAE Finite Element Analysis

Material / Properties	Stainless steel	Nickel plate	Mild steel
Force	189.87kN	161.819kN	95.416kN
Pressure	1678.83Pa	1430.79Pa	843.64Pa
Maximum stress	3644MPa	3106MPa	1831MPa
Minimum stress	46.97MPa	40.03MPa	2360MPa
Displacement	0.5416mm	0.4616mm	0.2722mm
Reaction force	525.1N	447.5N	263.9N

A comparison of result from three different materials, which is stainless steel, nickel and mild steel has been made to select the best material for the chain-link plate production.

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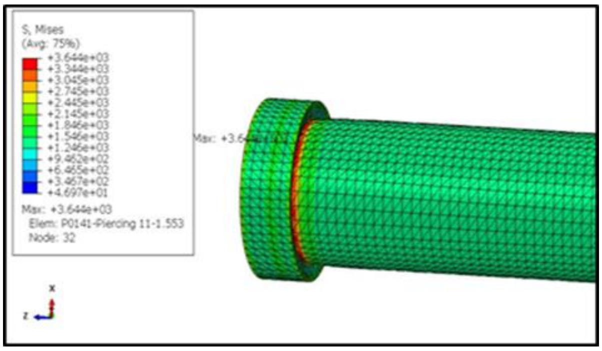
As from the finite element method result, the best material available for the chain-link plate is mild steel. This is due to the reason that mild steel possesses the characteristic of the lowest stress needed for piercing. This means that the mild steel plate is the most comfortable material to deform for the production. The value of stress needed is only 1831MPa compared to 3644MPa for stainless steel and 3106MPa for a nickel. As for the result of displacement on the punch, mild steel material produces the lowest displacement value on the punch with the only 0.5416mm. The other two materials which are nickel and stainless steel produce displacement of 0.4616mm and 0.2722mm each.



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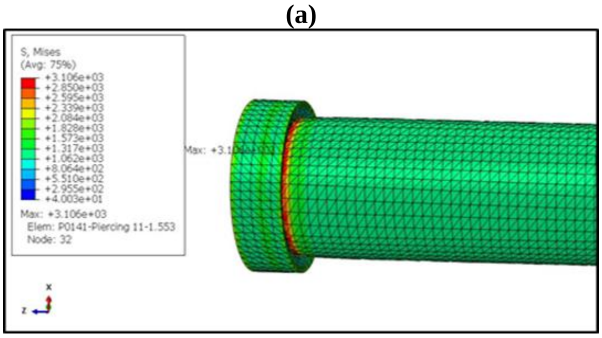

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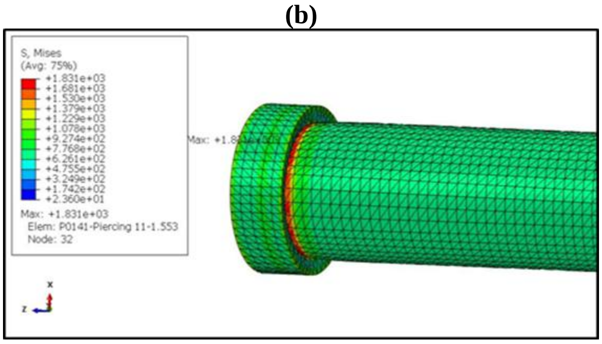

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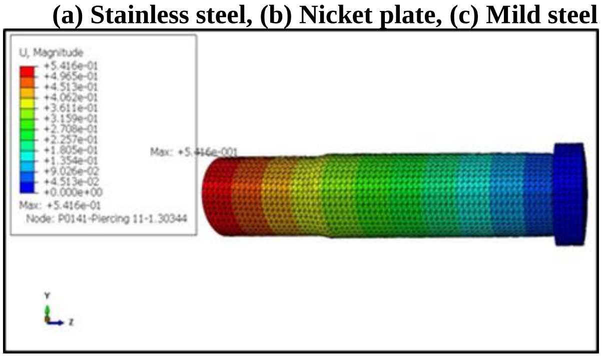
Fig. 5.Result stress from ABAQUS / CAE
(a) Stainless steel, (b) Nicket plate, (c) Mild steel



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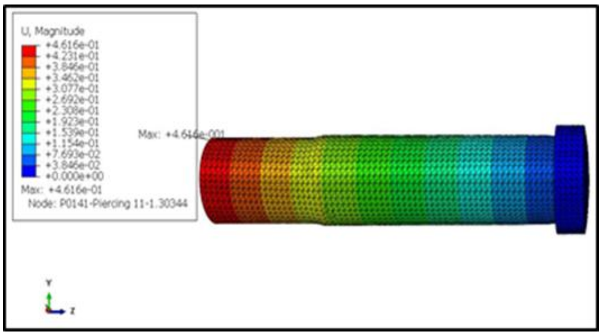

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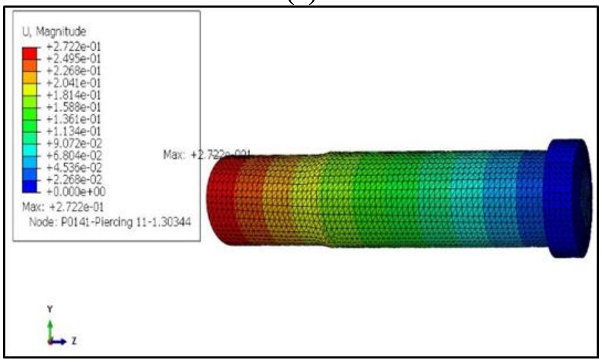

(c)

Fig. 6.Result displacement from ABAQUS / CAE
(a) Stainless steel, (b) Nicket plate, (c) Mild steel

From the stress values obtained, the life cycle prediction is then calculated by using E-Fatigue. For this reason, the best material, which is a mild steel lifetime cycle result produces about 19100 cycles in a lifetime. This means that the punch will be able to pierce 19100 unit of mild steel into the chain link plate before it fails due to crack. Meanwhile, the life cycle prediction for another two material produces the lower result of 9890 cycles for nickel and 8540 cycles for stainless steel each. From the overall simulation and analysis were done in this project, we can determine that the stress value of material will inversely proportional toward the punch lifetime cycle. Graph 1 shows, a higher number of cycle is achieved when the maximum stress is lower.

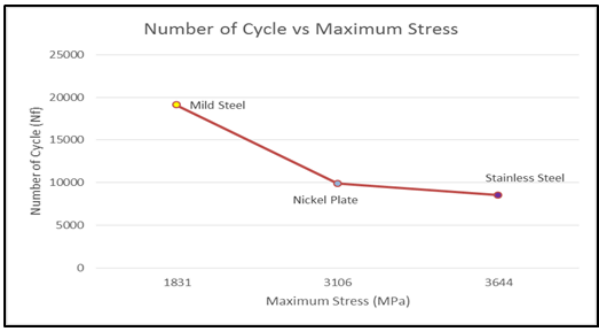

Fig. 7.Number of cycles against maximum stress

V. CONCLUSION

The progressive dies design and analyze of punch component is a challenge for die industry, which requires an effective design of the die process. Besides, the optimisation of the material selection is often in conflict for the punch design.

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For a progressive die for punch had to be designed efficiently to achieve an accurate result. This paper also presents some analysis data by using the ABAQUS/CAE to get the best material to improve the life cycle of punch. The purpose of this paper is to design a new 3D modelling of sheet metal forming die, to optimise a new chain link plate material to improve the performance of the punch component and to analyse the sheet metal punch to increase the punch lifetime cycle. From the result analysis, the conclusion can be found as follows.

- The result of the die design of progressive die has been constructed by using the 3DQuickpress. This also the problematic part component such as top plate, stripper plate and bottom plate have been designed. However, part of the strip layout had been creating with three stations by using SOLIDWORK, and the output of the product for one process can produce for 2 unit. Since for this process that is used a piercing punch and notching punch to create a chain link product.
- After progressive die design had been done, analysis data of punch design has been tested to improve the life cycle of punch by using ABAQUS/CAE. As a result. The decrease of maximum stress of the punch can be more prolonged of the life cycle of punch. Thus, mild steel is the best choice between those stainless steel and nickel plate because the maximum stress for mild steel is 1831MPa.

Consequently, it results also a reduction in displacement and reaction force. Because of this, the displacement and reaction force for mild steel is 0.2722mm and 263.9N. The impact force for this punch to the plate is lower than other material. It also decreases punch deflection and also can be produced in the industry.

- The E-fatigue was applied to verification and validation of all proposals to improve the life cycle of punch. The E-fatigue has been successfully developed as a result of this final year project. This website is very suitable and recommended for designing or rearranges the performance life cycle of stress material selection. This website also will give the data that more accurate rather than using calculation. Moreover, the best material lifetime cycle is mild steel. Because of that, the cycle time of mild steel is 19100 cycles better than stainless steel and nickel-plated.

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