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Design and Analysis of Stage Progressive Die for a Sheet Metal Component

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Abstract*: Stamping die industries had been a significant impact on research and development of new technology for bigger and advance. To sustain the stamping die industry under the current global situation, cost and time are most important factors that need to be focus. In this case study, the main problem of design and analysis of progressive die is cost spent for die fabrication is high, the number of station or stages is high that will affect the production time and lifespan of tool is short. This paper focused at the stages or station that will be redesign to reduce the cost for the die, station optimization to reduce time taken for stamping process and simulate the design of tools to calculate the life cycle of punch. The study is conducted through AutoCAD and Solidwork to redesign the die and strip layout optimization. Subsequently, the ABAQUS/CAE and e-fatigue are used to completed the analysis and life cycle results for punch with various design of punch edge. Theoretical analysis indicates that design of punch plays a vital role in life cycle analysis.

Keywords: Progressive die, lifespan, station optimization AutoCAD, ABAQUS/CAE.

I. INTRODUCTION

Production of progressive die from a workpiece follows numerous steps. At every stage, many die processes, namely piercing, notching, blanking, coining, shaving, drawing, and forming, are carried out on the sheet metal strip. The output is a complete workpiece at each stroke of the press. Due to the viable efficiency and achievement, progressive dies for creating sheet metal portions in mass manufacture is extensively applied in various industries such as aerospace, electronics, machine tools, automobiles, and refrigeration. Nevertheless, the structure of a progressive die is intricate, and the design cycle is lengthy. Nowadays, metal stamping industries had been a significant impact on research and development of new technology for bigger and more advanced. The metal imprinting is a process that proficient of producing mass production of parts that are consistent in dimensional size, quality and appearance. The number of station or stages in the die is depending on the complexity of the product if the product is more complex the number of stations will be increased too. It is also being produced with the complex assembly of die that consists of several of plate from upper section, middle section and lower section of die according to the product and process station that need. The connections numerous factors to the die production with an optimized method are focused by tool engineers. The critical role of tool designers is strip procedure layout design and computer-aided Finite Element Method (CA-FEM) simulation with an existing database and abundant field experiences.

So, both cost and time are most important factors that need to be focus before put it in the production section to run the mass production. The die was roughly designed and fabricated the output was insufficient. It is because most of the research studies stated were either focused on design, process scheduling or mechanization of the product. However, that is not much focus given for optimizing the design of complex progressive tools with huge count of stages. For this study, there are several problems that come out to face. Firstly, the number of stations may affect the cost of producing tools and die because the higher the number of station or stages, the die will be more complicated and more significant. Such as, it needs more standard part and bigger dimension size of plate or die. Besides, the higher number of stations also affect the production time during the forming process or stamping process. For example, if the progressive die has six-station, it is more time consuming than five stations. It can be reduced by optimizing the process and station by developing new design of strip layout. Lastly, the lifespan of tool is short because of many processes to do during forming process that increase the risk of failure. The tools or die will have a minor cracking or chipping at the edge of tools and die and the material of the tools and die. Then, there are several objectives of this study to counter the problems. Firstly, to redesign the process to reduce the cost. To optimizing the number of stations for forming process to reduce time. To simulate the design of tools to ensure the lifespan of tools is high.

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This study also will be focusing on simulation of the tools and die to ensure the lifespan of them. It can save money and time if we optimized all of it and can get a better result and visualization before any things happen.

The scope of this project is focusing on 3D modelling design of progressive die by using SOLIDWORK software. After that, die structure will be simulated by using finite element method software.

Certainly, the same concept that takes place in which blanking or in piercing or in any other shearing process. The shearing procedure, is carried out in four important stages. (Vishwanath & L, 2013)

Stage I: Plastic Deformation: When the stock item is mounted on the die, and the punch is rolled over the die. The punch impacts the stock material and pressure is applied over it. When the elastic limit of the stock material is surpassed, plastic deformation happens.

Stage II: Penetration: When the ram is driven by the driving force, the punch starts to stab the stock material, and the blank is displaced into the die opening. This is the real shearing part in the cutting series, and is named "shearing action".

Stage III: Fracture: Due to the pressure, at the cutting edge of the punch and die, fractures start to occur. Under proper cutting circumstances, the fractures propagate and join each other. Once this happens, the fracture is wholesome, and the blank is detached from the stock material. The punch now moves forward the die opening, and pushes the blank to some extent under the die cutting edge.

Stage IV: Stripping: Upon the hit, up to the lower point the punch is completed, and the blank is pushed over the die opening. This act is an aftershock at the fracture stage III and only in specific case, the push over happens where the punch goes beyond the area of the die. This is the upfront method of the shearing procedure. Before any other action, the focus shifts on few associated factors that call for more deep discussions on the shearing procedure.

The tolerance series postulates the total nonconformity a part can have and still be tolerable and function well inside an assembly (Suchy, 1998). Dissimilar manufacturing arenas use a diverse tolerance range. Where ±0.031 in. (0.79 mm) can be intolerable in die work, the similar tolerance range is too close-fitting for, in steel constructions.

Table- I: Selected Basic tolerance range (IT) values (Metric)

Dimension range (mm)		Basic tolerance range in micrometers (μm) Levels of accuracy				
From	To	1	2	3	4	5
3	6	1	1.5	2.5	4	5
6	10	1	1.5	2.5	4	6
10	18	1.2	2	3	5	8
18	30	1.5	2.5	4	6	9
30	50	1.5	2.5	4	7	11

The progressive die is very intricate, and even a normal progressive die may have numerous components. (Shailendra, 2001) Key mechanisms of a progressive die are block, front spacer and back gage (die gages), punch plate, stripper plate, punches, backplate, pilots, die-set and closures. The mechanisms of a progressive die can be divided into two clusters. The first contains punches, pillars, fasteners, die-set, and die button, that are industry standard components that can be organized in standard dimensions. The second consist of punch plates and special punches.

Punch Holder: The punch holder is also known as an upper-die shoe. It holds the punch. The punch is fitted in the taper hole provided in the shank of the holder. This part grips and chains the dissimilar punches in place. Usually stack under backup pressure and top plate.

Stripper Plate: This is used to clutch the material down on the slug die and shred the material of the hits. They are used to eliminate the stock from the punch after a blanking or piercing process and grouped as spring operated and fixed. Fixed strippers are firmly fixed to the die shoe. Spring operated strippers move up and down on the shank of the punch. Stripper plate grips the specimen on the die when the tool strips the material.

Thrust Plate: Observes the upward thrust of the punch. Prevents from digging into the punch holder. Thrust plate also used to hold the strip in place before the punch reach and perform cutting or stamping process.

Guide Pin, Bushing, Back Gauge: These are the mechanisms to lead the tool to the required path. These parts confirm how the tool moves in the similar location in every single stroke of action in the die.

Ground Block: Ground block is also known as a bottom plate; the purpose of ground block is to hold cutting plate in place and attached to the sub-block and lower clamping plate. This block provides softening effect to the die. Opening in the Baseplate lets the blank to give way of the tool. Typically, made out of mild steel or cast iron.

FEA is a method to solve, specific problems in engineering and science. It is applied for problems for which no exact solution, expressible in some mathematical form, is available. FEA is a numerical method. Abaqus/CAE is categorized into functional units named as modules. Each module contains only those tools that are relevant to a specific portion of the modelling task. For instance, the Mesh module comprises only the tools required to create finite element meshes, while the Job module encompasses only the tools used to generate, edit, submit, and monitor analysis jobs. Abaqus/Viewer is a subset of Abaqus/CAE that covers only the Visualization module.

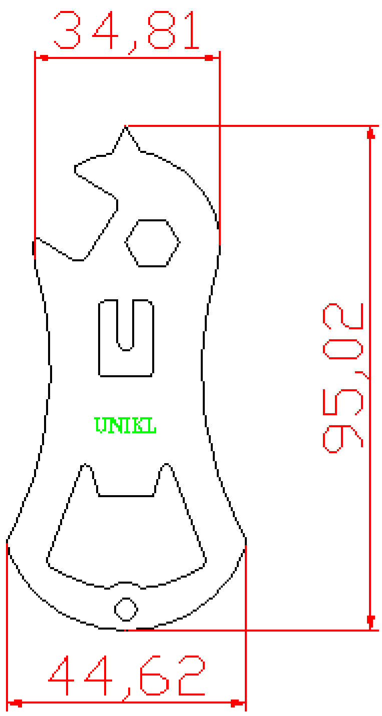
II. METHODOLOGY

This chapter describes the method and techniques used to accomplish the project of Design and Analysis of Multistage Progressive Die for A Sheet Metal Component. This chapter consists output of the new design of station and die structure such as upper die and lower die. The primary purpose of the methodology was to ensure that the project is well arranged along the development of the project to be successful. Therefore, a simplified phase by phase method was proposed.

A. Project product

The product chosen for the project is a Multi-purpose bottle opener. The multi-purpose bottle opener is made up of aluminum that have thickness of 2mm. The product has several function and features, the purpose is bottle opener, letter opener, nut screw opener with specified size and can opener.

(a)

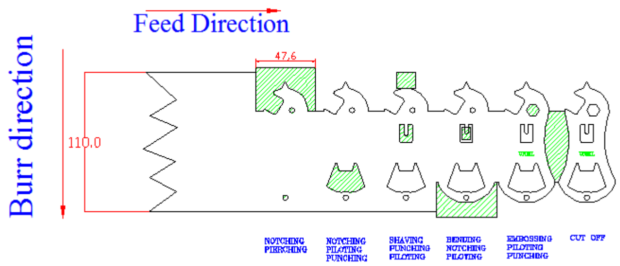


(b)

Fig 1: Project Product. (a) 3D model (b) 2D model

B. Redesign strip layout comparison

In figure (a) shows that the number of stations is six, for the first station usually is stating with notching and piercing process. The purpose of the notching process is to make the station at sheet metal fixed to the measurement that desired, and the piercing process is to make a hole for piloting operation for the second stage. At the second stage, process that been operated is punching and piloting. Punching a detailed profile for the bottle opener, and piloting is to hold the sheet metal before stamping operation because the sheet metal needs to be aligned with the position before performing the stamping. Next, the third stage process that had been performing is punching and shaving. Punch a profile for can opener and shaving process at the top of product for making it sharp to open a can or letter. For the fourth stage, notching and bending were performed. Notch the profile for the shape and bend the centre of the feature for the can opener. For the fifth stage, embossing and punching for the text and the nut shape. Lastly, the final process is cut-off process to separate the finished product from the strip layout or sheet metal. In figure (b) The optimisation is made for the strip layout design where is one station has been removed and became five stations. Start from the fourth stage until the last stage is drag one stage forward.



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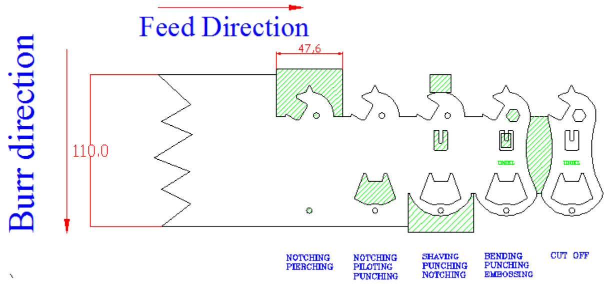


(b)

Fig. 2: Strip Layout Comparison. (a) Previous Strip Layout (b) Redesign Strip Layout

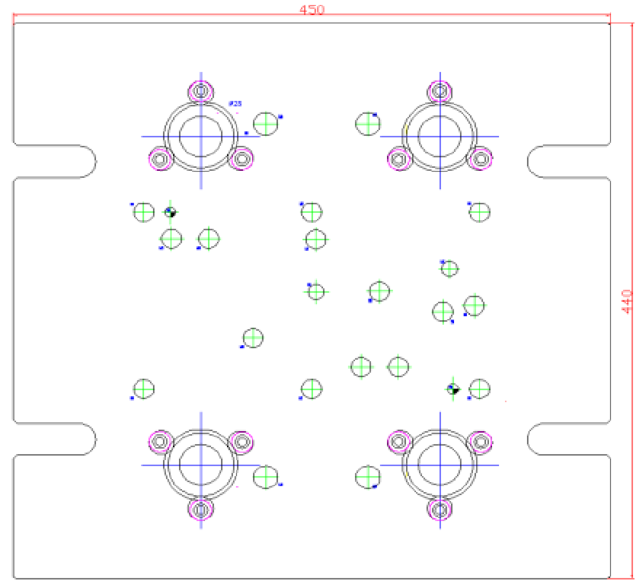
C. Progressive die component redesign

In this subtopic, all component of the progressive die will be shown in 2D drawing in the AutoCAD software. The drawing will be compared side by side in the form of figures. The progressive die is divided into three sections, which is upper die, middle die and lower die. All the die component has been reducing the size by 47.6mm because of removing one of the stations.

Upper Die – upper die component it consists of a top plate punch holder and backup pressure plate.

Middle Die – For middle die component it consists of stripper plate and thrust plate.

Lower Die – consists of a ground block, cutting plate, guide fence, sub-block and lower clamping plate



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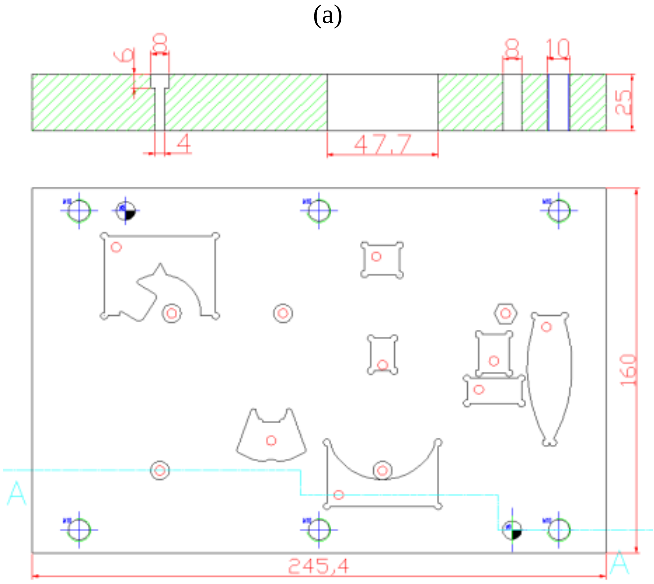

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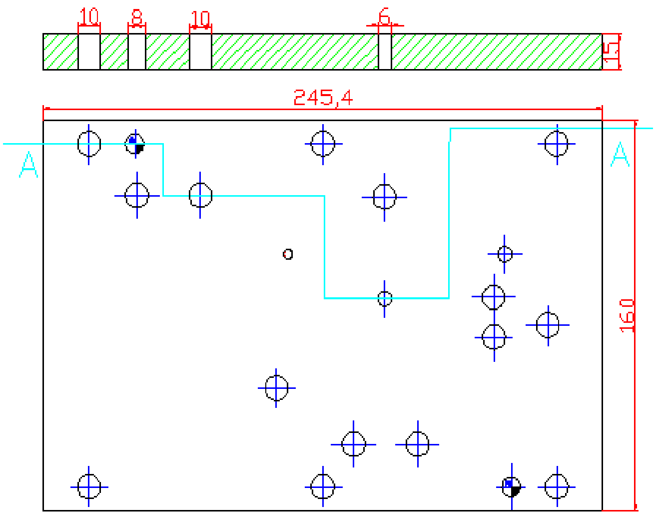
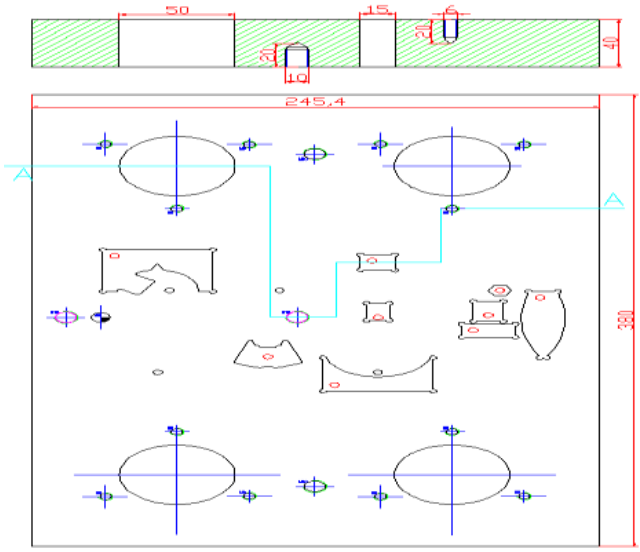


(c)

Fig. 3: Redesign Upper die. (a) Top Plate (b) Punch Holder (c) Backup Pressure Plate



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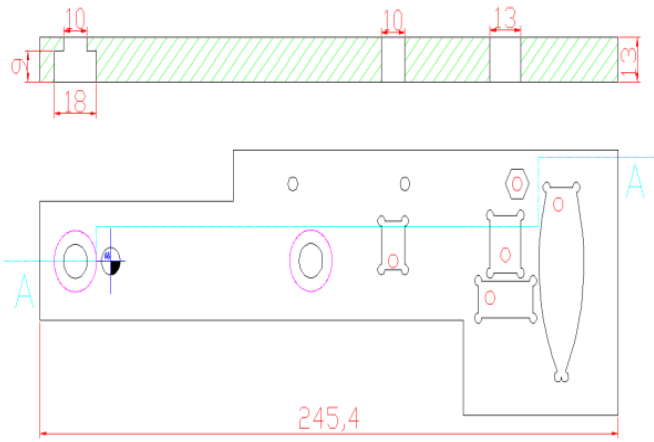
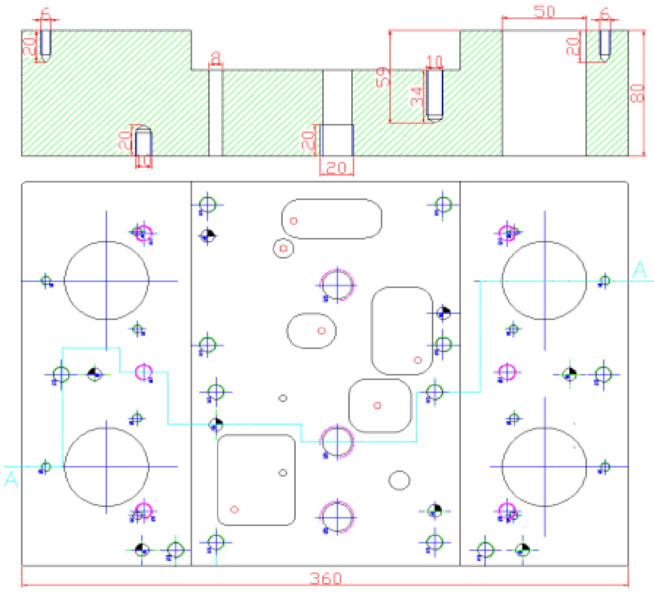


(b)

Fig. 4: Redesign Middle die. (a) Stripper Plate (b) Thrust Plate



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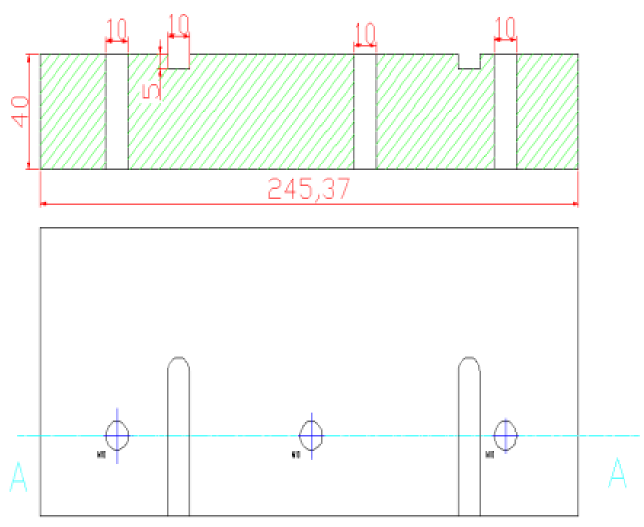

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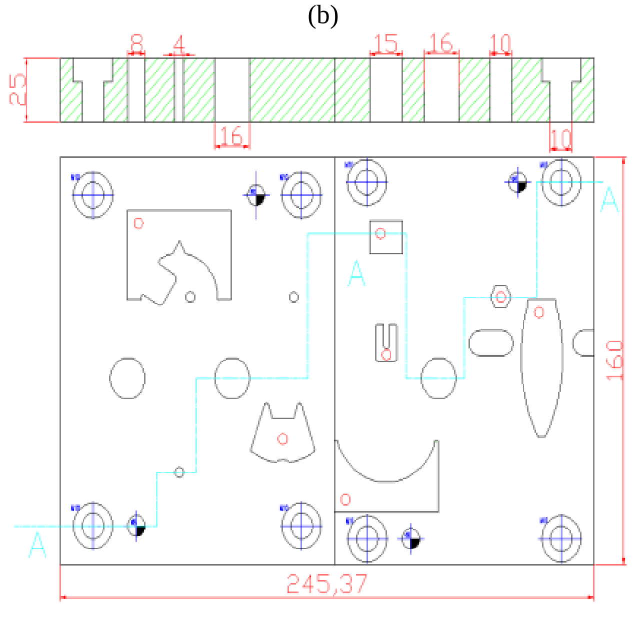


(c)

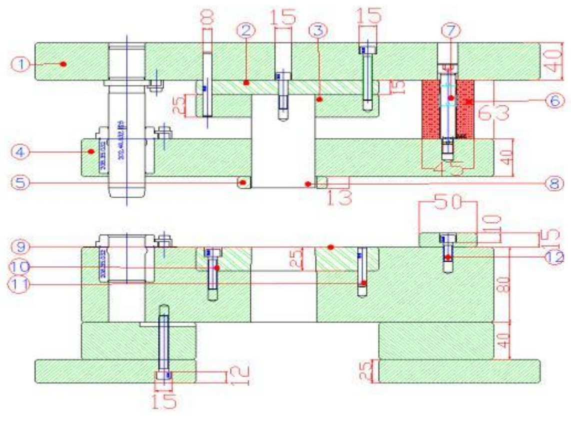
Fig. 5: Redesign Lower die. (a) Ground Block (b) Sub-block (c) Cutting Plate

D. Assembly cross section & bill of material

In this part, will be showing the assembly of a complete die in three-dimensional (3D) cross-section for the complete die will show in the figure below and will be numbered and listed in a table by part. The standard part such as an elastomer, bolt screw and thickness of each plate will be shown in figure.

E. Stamping calculation

Stock material preservation is a decisive factor in means should be tried to attain this without sacrificing the piece part. The economic factor is also known as material utilization. The economy of any strip layout in percentage is found out by the following formula



(a)

NO	ITEM	MATERIAL	DIMENSION
1	Top Plate	MILD STEEL	450 X 440 X 40
2	Backup Pressure Plate	DC 53	293 X 160 X 15
3	Punch Holder	MILD STEEL	293 X 160 X 25
4	Stripper Plate	MILD STEEL	293 X 360 X 40
5	Thrust Plate	DC 53	293 X 78 X 13
6	Elastomer	STANDARD	AAX 45-63 ID14
7	Stripper Bolt	STANDARD	MSB 13-70
8	Cut Off Punch	DC 53	100 X 56 X 20
9	Cutting Plate	DC 53	160 X 293 X 25
10	Cap Screw	STANDARD	CB 8-35
11	Dowel Pin	STANDARD	MSTM 8-40
12	Cap Screw	STANDARD	CB 8-20

(b)

Fig. 6: (a) Assembly Cross-section (b) Bill of Material

. All calculation was calculated by using formula;
Material Utilization,
Economic Factor = $A \ x \ R \ / \ B \ x \ V$ 100% (1)
A =Blank area (mm2)
R =Number of rows per strip
B =Width of strip
V =Pitch of strip

Cutting Force, F=L x T x (2)
Where:
F =Cutting force
L =Total length of the cutting edge (perimeter punch)
T =Material thickness
σs =Shear strength

Total Force = Cutting Force + Bending Force (3)
Stripping Force = 10% x Total Force (4)

F. Finite element method

The succeeding list of the modules accessible inside Abaqus/CAE briefly defines the modelling tasks you can achieve in each module. The order of the modules in the list resembles to the order of the modules in the context bar's Module list and the Model Tree: (Systèmes, 2014)

- Part - Create separate parts by sketching or introducing their geometry.
- Property - Create section and material definitions and assign them to regions of parts.
- Assembly - Create and

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assemble part instances.

- Step - Create and describe the investigation steps and associated output requests.
- Interaction - Specify the interactions, such as contact, between regions of a model.
- Load - Specify loads, boundary conditions, and fields.
- Mesh - Create a finite element mesh.
- Optimization - Create and organize an optimization task.
- Job - Submit a job for analysis and monitor its progress.
- Visualization - View analysis results and selected model data

G. Life cycle fatigue

All structures and mechanical mechanisms that are cyclically loaded can fail by fatigue. With limited input data, constant amplitude fatigue analysis is used to make a quick and straightforward approximation of the likely fatigue performance or Durability. There are numerous approaches for approximating the fatigue resistance of mechanisms and structures. Stress-Life The study assumes that the stresses constantly keep on elastic even at the stress concentrators. Fatigue occurs when a material is Subjected to repeated loading and unloading. There are several criteria that need to fill before running the fatigue stress-life calculation:

Step 1: Loading (Maximum and Minimum Stress)
Step 2: Material
Step 3: Modifying Factors
Step 4: Stress Concentration Factor
Step 5: Obtain a result of Life-Cycle for punch

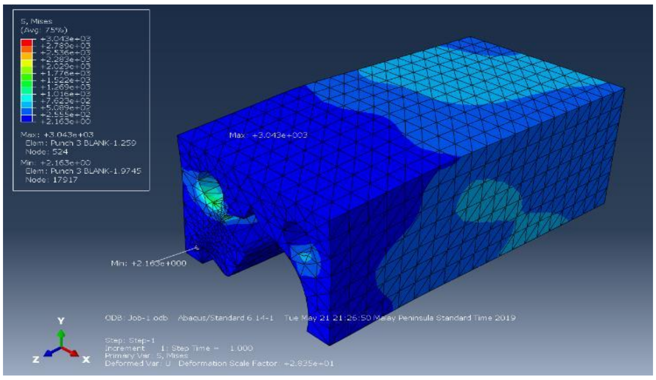
III. RESULT AND DISCUSSION

Table 2 below shows all the results that had been obtained from the Abaqus/CAE Finite Element Analysis (FEA). The results that shown below is the value of the maximum and minimum analysis for stress, displacement and reaction force from blanking punch design 1, 2 and 3 respectively. All the force and pressure that had been applied to the punch is same because the area that had been calculated is the same. However, the data for stress, displacement and reaction force is different because the design of the edge of each punch is different.

Table- II: Results for a maximum value of the properties for three different design of edge

The shape of Edge / Properties	Design 1	Design 2	Design 3
			
Stress	3043MPa	3169MPa	5058MPa
Displacement	0.4462mm	0.4455mm	2.4810mm
Reaction Force	13.91kN	13.25kN	22.91kN

For the comparison, it is between three conceptual design flat surface, square edge and fillet edge surface on two different blanking punch. Blanking punch first stage and third stage. From the Abaqus/CAE analysis result, the stress value between three design of first stage blanking punch is 3043MPa for the first design, 3169MPa for other design and 5058MPa for the third design. For displacement perspective, another design Is the lowest value of displacement, 0.4455mm, first design is 0.4462, and third design is 2.481mm.



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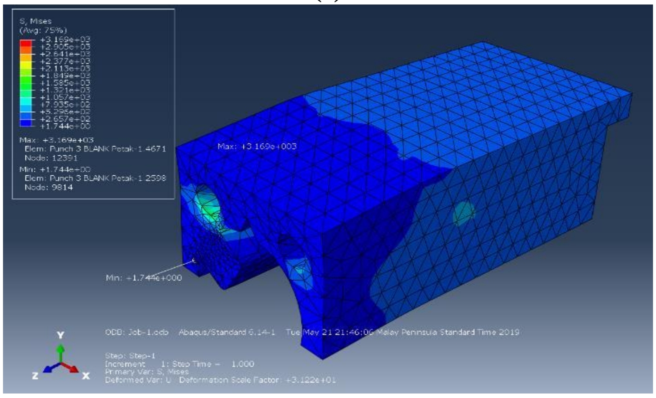

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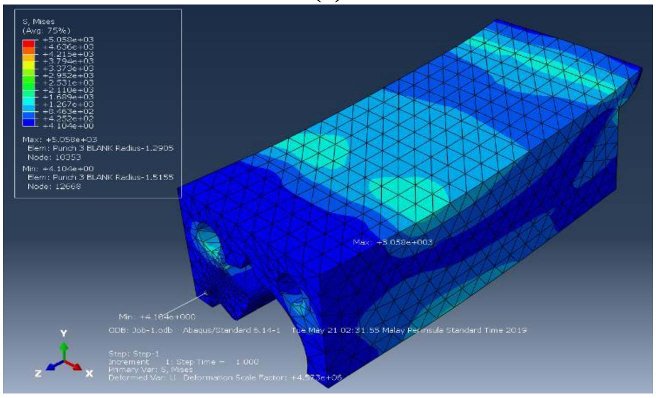

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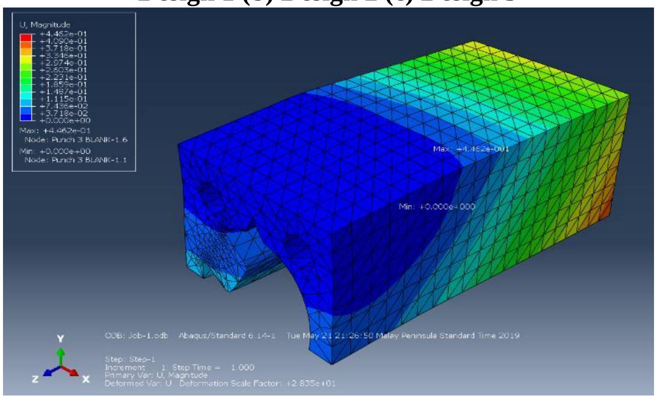
Fig. 7: Analysis result stress for different design. (a) Design 1 (b) Design 2 (c) Design 3



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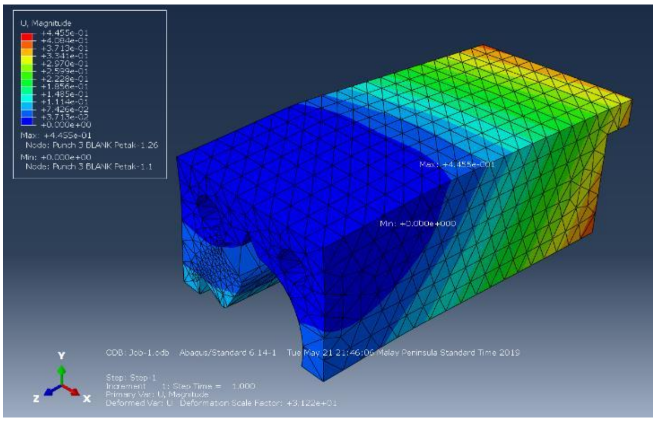

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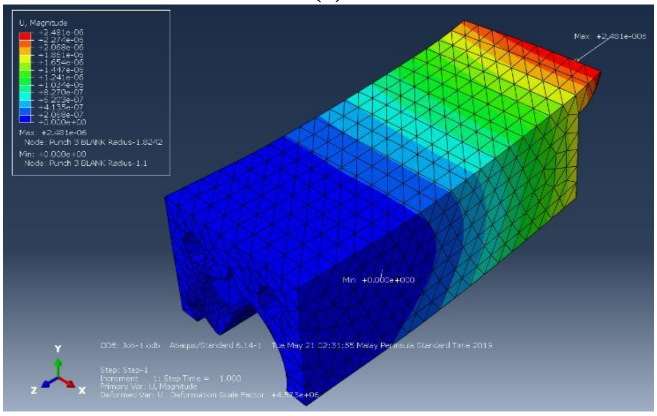


(c)

Fig. 8: Analysis result displacement for different design. (a) Design 1 (b) Design 2 (c) Design 3

From the stress value that had been obtained, the life cycle of punch is calculated by using E-fatigue. The best result That comes out for life cycle is second design blanking punch is about 22500 cycle before failure. Meanwhile, the other two the design which is first design and third design, resulted with 20300 cycles and 7880 cycles respectively.

IV. CONCLUSION

In this case study, the main problem and challenges are design and analysis of progressive die. A huge variety of sheet-metal forming processes is used in modern sheet-metal press-working shop practice. The entire objective is about to reduce the cost; time is taken for production and lifespan of punch. Both cost and time are most important factors that need to be focus before put it in the production section to run the mass production. This project also presents the analysis results from Abaqus/CAE and e-fatigue to gained the life cycle for punch. First and foremost, the progressive die design was modelled by AutoCAD for two-dimensional (2D) drawing and for three-dimensional (3D) drawing has been designed by using 3D Solidwork Logopress. Designed and re-design progressive die can be considered as a huge challenge because the structure is too complex. Progressive die component is divided into three sections, Upper die, middle die and lower die. Stage optimisation was achieved by reducing one stage from six stages to five-stages.

Analysis Results

N_f = 22500

Specified

- S_{max} or e_{max} = 3169 MPa
- S_{min} or e_{min} = 1.744 MPa
- Material Type = other
- Material Name = DC 53 Tool Steel
- S_u = 2500 MPa
- E = 209900 MPa
- Surface Finish Type = none
- Loading Factor Type = axial
- K_t = 2.5
- Use Fatigue Notch Factor = No
- Mean Stress Definition = Maximum Stress

Default

- S_{FL} = 1250 MPa
- N_{FL} = 1.00E+06
- S_f' = 4040 MPa
- b = -0.085
- k_{SF} = 1.000
- k_L = 1.000
- k_{size} = 1.000

Calculated

- S_{min} or e_{min} = 2 MPa
- S_a or e_a = 1584 MPa
- S_m or e_m = 1585 MPa
- S_m = -784 MPa
- S_{eq} = 888 MPa
- b_{eq} = -0.151

(a)

Analysis Results

N_f = 20300

Specified

- S_{max} or e_{max} = 3043 MPa
- S_{min} or e_{min} = 2.163 MPa
- Material Type = other
- Material Name = DC 53 Tool Steel
- S_u = 2500 MPa
- E = 209900 MPa
- Surface Finish Type = none
- Loading Factor Type = axial
- K_t = 2.2
- Use Fatigue Notch Factor = No
- Mean Stress Definition = Maximum Stress

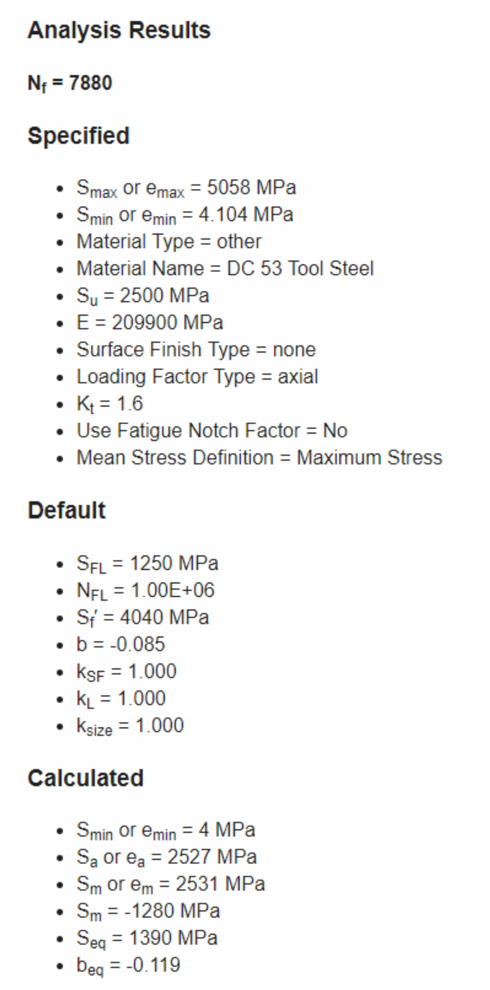
Default

- S_{FL} = 1250 MPa
- N_{FL} = 1.00E+06
- S_f' = 4040 MPa
- b = -0.085
- k_{SF} = 1.000
- k_L = 1.000
- k_{size} = 1.000

Calculated

- S_{min} or e_{min} = 2 MPa
- S_a or e_a = 1520 MPa
- S_m or e_m = 1523 MPa
- S_m = -611 MPa
- S_{eq} = 989 MPa
- b_{eq} = -0.142

(b)


Analysis Results

N_f = 7880

Specified

- S_{max} or e_{max} = 5058 MPa
- S_{min} or e_{min} = 4.104 MPa
- Material Type = other
- Material Name = DC 53 Tool Steel
- S_u = 2500 MPa
- E = 209900 MPa
- Surface Finish Type = none
- Loading Factor Type = axial
- K_t = 1.6
- Use Fatigue Notch Factor = No
- Mean Stress Definition = Maximum Stress

Default

- S_{FL} = 1250 MPa
- N_{FL} = 1.00E+06
- S_f' = 4040 MPa
- b = -0.085
- k_{SF} = 1.000
- k_L = 1.000
- k_{size} = 1.000

Calculated

- S_{min} or e_{min} = 4 MPa
- S_a or e_a = 2527 MPa
- S_m or e_m = 2531 MPa
- S_m = -1280 MPa
- S_{eq} = 1390 MPa
- b_{eq} = -0.119

(c)

Fig. 9: Analysis result for lifecycle punch. (a) Design 1 (b) Design 2 (c) Design 3

Next, after completing the previous design step, this process was proceeded with Abaqus/CAE to obtain the value of properties such as maximum and minimum value of stress and displacement to insert the value in the e-fatigue. Two of the blanking punch was selected to be analysed with three different conceptual design of bottom surface of blanking punch. As a result, the best result that comes out for life cycle for first stage blanking punch is second design blanking punch is about 22500 cycle before failure. Meanwhile, the other two design which is the first design and third design resulted with 20300 cycles and 7880 cycles respectively. Meanwhile, for the third stage of blanking punch, the highest life cycle among the design is another design with 17500 life cycle compared to other two design, first design is 16600 life cycle, and third design is 2940 life cycle.

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