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Progressive Die Design for Self Explosive Reactive Armor Holder (Case Study at Bishoftu Motorization Industry-Ethiopia)

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ABSTRACT

Bishoftu motorization industry currently assembles Tank 55 model and Tank 62 model which are not using self explosive armor as Tank 72 model, because the part is costly and imported from overseas. Currently the company needs to cover the previous two models by self explosive reactive armor, these tanks needs one hundred fifty units each to cover the body of the tanks with self explosive reactive armor.

This research deals with designing a progressive die, simulating the stamping process, analyzing stress and displacement of the components of die which is used for manufacturing self explosive reactive armor holder. A progressive die performs a series of fundamental sheet metal operations at two or more stations during each press stroke in order to produce the part as the strip stock moves through the die. In this work a progressive die design which consists of five stations in order to produced self explosive reactive armor holder by using solidWork 2012 software for the modeling of parts and logopress3 which is an add on software on solidWork 2012 to the simulate stamping operation and validation of the design process.

The designed die can help Bishoftu motorization industry to manufacture the part rather than importing from abroad, hence it will save hard currency. One of the major constraints to determine the number of stages of the progressive die is operation to be performed on the part, the existing press machine tonnage capacity and geometrical dimensions. These requirements and constraints are considered so that the designed machine tool meets its functional necessities.

KEYWORDS: *Progressive Die Design, Self Explosive Holder, Bishoftu Motorization Industry, Logopress3*

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I. INTRODUCTION:

Now a day's a very large variety of sheet metal forming processes are used in modern sheet metal product manufacturing company. Many of these sheet metal forming processes are used in making the parts of aircraft, automobile, ship, and other products, by using complex equipment derived from the latest discoveries. With the ever increasing knowledge of science and technology, future deformation processes promise to be even more intricate to meet the need for high productivity, cheap price, and greater accuracy. However, for the unique advantages, the more sophisticated deformation processes of today have not replaced the need for basic sheet metal forming processes and dies [1].

Sheet metal stamping dies are used for both serial and mass production. Their characteristics are: high productivity, optimal material usage, easy servicing of machines, not required skilled operator, and economic advantage. Parts made from sheet metal have many attractive qualities: good accuracy of dimension, ample strength, light weight, and a broad range size is possible to manufacture [2].

Explosive reactive armor (ERA) is in use since the last 20^{th} century and it was originally designed to defeat high explosive armor piercing warheads. An explosive package for use in a reactive armor construction, side package comprising an explosive material embedded between layers of a resilient material, side layers of resilient material being contained between upper and lower rigid plates in a sandwich structure. The aim of this research is to design progressive die for tank self explosive reactive armor holder, by performing analysis for the critical parts of the die analytically and validating the results using commercially available software.

II. TYPES OF DIE CONSTRUCTION:

Stamping dies are classified by the type of construction of the dies are compound die, combination die and progressive die.

2.1 Compound Die

Compound dies produce very accurate parts, but their production rate is quite slow. These dies consist of a single station where the part is most often blanked out and either formed, embossed, pierced, or otherwise adjusted in a single stroke of the press. No progression of the strip is involved, as each strokes of the press produces a single complete part. Combination dies combine at least two operations during each stroke of the press. Some compound dies are used just for trimming others are specialized for blanking.

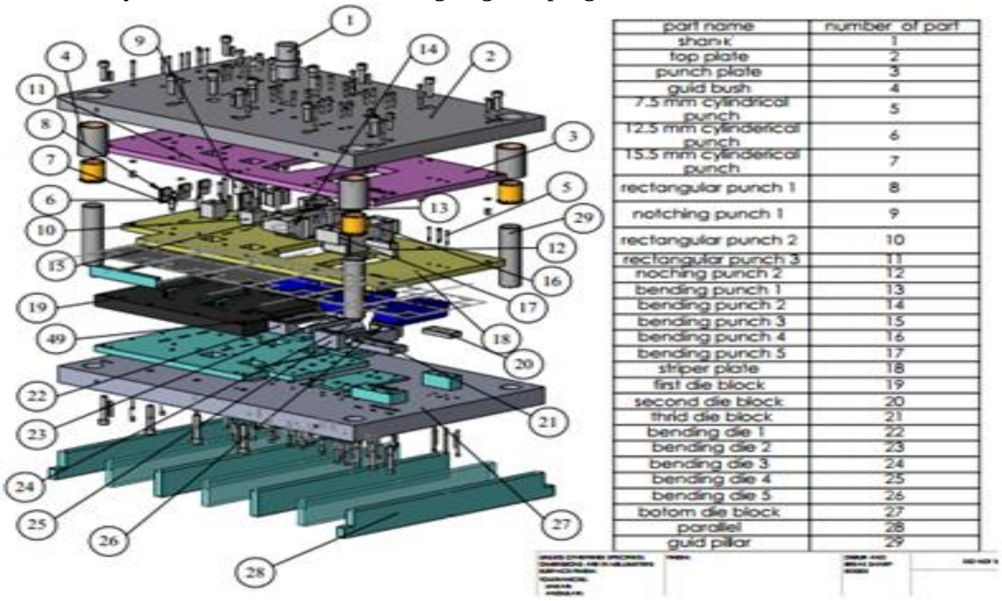
2.2 Combination Dies

Combination die combine at least two operations during each stroke of the press. Some shops, however, are making a distinction between the two types calling any cutting and forming die a combination die, while the compound die is considered only a cutting die.

2.3 Progressive Die

A progressive die performs a series of fundamental sheet metal operations at two or more stations during each press stroke in order to develop a work piece as the strip stock moves through the die. The work piece on progressive dies travels from one station to another, with separate operations being performed at each station. Usually the work piece is retained in the stroke until it reaches the final station, which cuts off the finished piece. All stations work simultaneously at different points along the work strip, which advances on station at each stroke of ram. Thus a complete part is produced with each stroke. Progressive dies generally include blanking and piercing operations but a complicated progressive die can do the operation of bending, forming, curling and heading also. Each workstation performs one or more distinct die operation, but the strip must move from the first through each succeeding station to fabricate a complete part [2].

Among the above types of die construction progressive die is ideal alternative to manufacture self explosive reactive armor holder having many operations like piercing, notching, pre bending, full bending and parting off, that is the reason why the researchers chosen designing of a progressive die construction.



part name	number of part
shank	1
top plate	2
punch plate	3
guid bush	4
7.5 mm cylindrical punch	5
12.5 mm cylinderical punch	6
15.5 mm cylinderical punch	7
rectangular punch 1	8
notching punch 1	9
rectangular punch 2	10
rectangular punch 3	11
noching punch 2	12
bending punch 1	13
bending punch 2	14
bending punch 3	15
bending punch 4	16
bending punch 5	17
striper plate	18
first die block	19
second die block	20
thrid die block	21
bending die 1	22
bending die 2	23
bending die 3	24
bending die 4	25
bending die 5	26
botom die block	27
parallel	28
guid pillar	29

Figure 1 Exploded assembly drawing of progressive die

III. MATERIALS FOR DIE COMPONENT:

Tool steels are used to construct the die components in a variety of press working operations which is subject to wear. If it is heat-treated these steels develop high hardness level and abrasion resistance [4].

Tool Steel Selection Guidelines

In forming and cutting operations of sheet metal parts, as in all industrial manufacturing operations, it is important that the production runs are trouble free. To achieve good productivity and tooling economy, selecting appropriate tool steel is crucial. To select the right tool steel for the application in question, it is vital to identify the mechanisms which can lead to premature tool failures. In forming and cutting operations there are five principal failure mechanisms:

1. Wear, abrasive or adhesive, related to the operation, the work material and the friction forces due to sliding contact between the tool and the work material.
2. Plastic deformation, which appears when the operating stress level exceeds the compressive yield strength (hardness) of the tool material.

3. Chipping, which is a result of high working stresses compared to the fatigue strength of the tool material.
4. Total cracking, caused by high working stresses compared to the fracture toughness of the tool material.
5. Galling (pick-up), due to heavy friction forces due to the sliding contact and the adhesive nature of the work material, the galling mechanism is closely related to adhesive wear

The whole system may not require high strength material; since some standard items are involved and it could be made from less expensive materials, the researchers categorize the selection of materials under three groups. The materials which are directly exposed to abrasion wear, materials used for structural purpose and standard items.

Tool steels are used to construct the die components subject to wear. They are used in a variety of press working operations. These steels are designed especially to develop high hardness levels and abrasion resistance when heat-treated. Selection of tool steel for a specific operation must be based on two major considerations:

i. Predicting the performance of the steel for an application and
ii. Analyzing the limitations associated with the manufacturing of tools and dies.

AISI D2 is a high-carbon, high-chromium tool steel alloyed with molybdenum and vanadium characterized by: high wear resistance, high compressive strength, high stability in hardening and good resistance to tempering back. AISI D2 material is the most widely used tool steel in most worldwide as well as Ethiopian industries. As described above under the discussion of material requirement and their final selection, D2 tool steel is available in their sister company (Metal Industry Development Institute, Addis Ababa, Ethiopia) specialized in die manufacturing. It also fulfills the requirements of the manufacturing of piercing and bending punches and dies plate. The remaining parts can be manufactured from a less expensive material, structural steel St-42 can best serve the purpose of structural parts.

IV. PROGRESSIVE DIE DESIGN:

The die set is one of the basic elements of progressive die consisting of a bottom plate and top plate together with guide pillars and bushes by means of which the top and bottom plates are aligned. The purpose of a die set is to utilize the entire die assembly. Some of the advantages realized by assembling die components to a properly selected die set are accurate die set up, better part quality, prolonged die life, minimum set up time, facilitation of maintenance, alignment of punch and die members and facilitation of storage.

The work piece on progressive dies travels from one station to another, with separate operations being performed at each station. Usually the work piece is retained in the stroke until it reaches the final station, which cuts off the finished piece [1]. To design the progressive die for the case company the constraints are the governing and limiting parameters; constraints like press tonnage capacity of the existing press machine in the company and its geometrical dimension so as to be compatible with the die.

4.1 Basic Data of the Reactive Armor Holder

The explosive reactive armor (ERA) holder is used for holding reactive armor in a sandwich form between two plates by using four M6 bolts from both sides of the flanged part so the reactive armor remains stationary during the movement of the fighting vehicles. The explosive holder attached to fighting vehicles by using six M12 bolts. ERA holder is made from mild steel sheet metal having shear strength 241 N/mm^2 and tensile strength of 275 N/mm^2. The size of the blank sheet to manufacture a single armor holder is 270 mm x 406 mm x 3 mm.

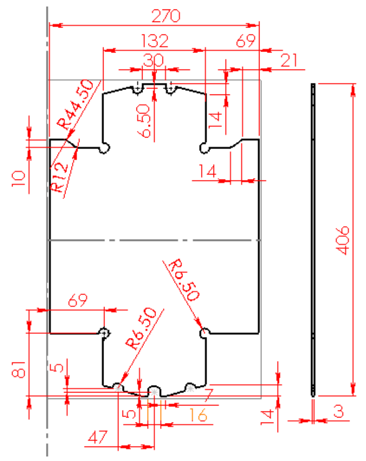


Figure 2 Features and dimension of explosive reactive armor holder before bending operation

4.2 Die Clearance and Tool Life

The standard allowance (die clearance) between the punch and die cutting edges depend upon the properties of the material to be sheared. Ductile materials should have lesser die clearance otherwise the soft metal will be drawn in to the gap. On the other hand, the harder materials need large die clearance for good shearing action. Excessive die clearance causes more burrs on the sheared component. Reduction in die clearance reduces the burr, but it accelerates the blunting of the cutting edges of dies and punches. Die clearance for shearing of mild steel sheet is recommended 2.5% to 5.0% of its thickness. That is:-

Minimum recommended die clearance = $\frac{2.5}{100}\ x\ 3mm = 0.075\ mm$

Maximum recommended die clearance = $\frac{5}{100}\ x\ 3mm = 0.150\ mm$

As the die clearance runs all around the piercing punch,

$$\text{Die bore} = \text{punch diameter} + 2\ (\text{die clearances/side}) \quad \ldots\ldots\ldots\ldots 1$$

Increase in die clearance increase tool life, doubling clearances from 2.5% to 5% (for mild steel sheet) doubles the tool life. So when the requirements of blanks dimensional accuracy are not very high, it is convenient to keep die clearance more and remove the excessive tensile burr on the blanks manually [5].

4.3 Force Analysis

1. Shear Force

The force required to be exerted by the punch in order to shear out the blank from the stock can be estimated from the actual shear area and shear strength of the material using formulae.

$$F = f_s\ x\ Ls\ x\ t \quad \ldots\ldots\ldots\ldots 2$$

Where f_s = shear strength of the blank material [N/mm^2]

L_s = shear length [mm]

t = thickness of the blank material [mm]

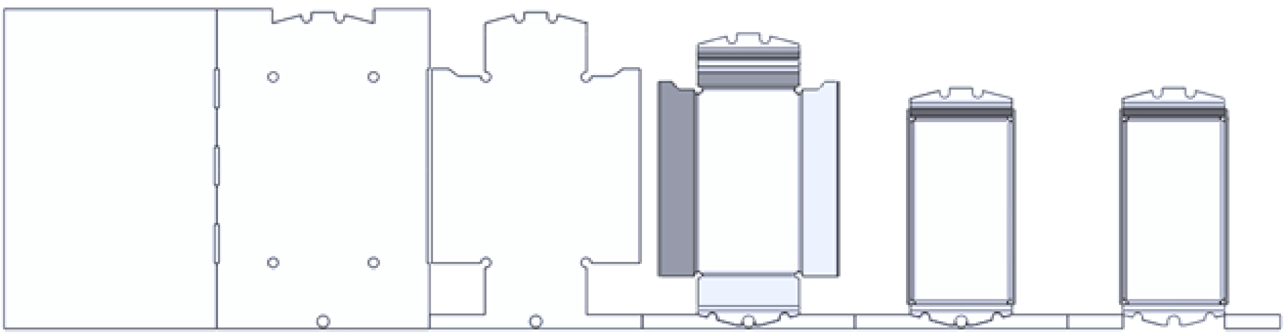


Figure 3 Stations (sequence of operation) of the explosive reactive armor holder

1. Shear force at station one (F_1)

   $F_1 = f_s\ x\ L_{s1}\ x\ t$

   $L_{s1} = 725$

   $F_1 = 241\ x\ 725\ x\ 3$

   $= 524{,}175$ N

2. Shear force at station two (F_2)

   $L_{s2} = 1{,}094$

   $F_2 = 241\ x\ 1{,}094\ x\ 3$

   $= 790{,}962$ N

3. Shear force at station five (F_5)

   $L_{s5} = 345$

   $F_5 = 241\ x\ 345\ x\ 3$

   $= 249{,}435$ N

The total shear force is the sum of shear force on each station.

$F_{\text{Total Shearing}} = F_1 + F_2 + F_5$

$F_{\text{Total Shearing}} = 1{,}564{,}572$ N

2. Bending force

The bending force will be calculated from the knowledge of material properties and the die characteristics.

For U channel bending $V_{bc} = \frac{2.66\,L\,t^2 f_t}{W} + P_{pad}$ ………………………………………………….. 3

Where V_{bc} = bending force

L = transverse length of the bend [mm]

t = thickness of the blank material [mm]

f_t = tensile strength of the blank material [N/mm^2]

W = width of channel [mm]

P_{pad} = 30% of the bending force $= 0.3 * V_{bc}$

1 Bending force calculation at station three

a) Bending in the transverse direction

W = 170 and L = 343

$V_{bc} = 1.3\,x\frac{2.66\,L\,t^2 f_t}{W}$ ………………………………………………………………………4

V_{bc} = 17,267 N

b) Bending in the longitudinal direction

W = 379 and L = 132

V_{bc} = 2,981 N

The total bending force on station three is the sum of transversal and longitudinal bending forces.

$V_{\text{Total bending force at station three}}$ = 17,267 + 2,9781

= 20,248 N

2 Bending force calculation at station four

a) Bending at the transverse direction

W = 140 and L = 242

= 14,794 N

b) Bending in the longitudinal direction

W = 250 and L = 132

= 4,519 N

The total bending force on station four is the sum of transversal and longitudinal bending forces.

$V_{\text{Total bending force at station four}}$ = 19,313 N

$V_{\text{Total bending force}}$ = 39,561 N

$F_{\text{Total}} = F_{\text{Total Shearing}} + V_{\text{Total bending force}}$

= 1,604,133 N

The recommended factor of safety is to increase the total force by 30%; therefore the required capacity of press will be 2,085,372 N = 213 tones which will suit to the existing machine.

4.4 Design of the Die Parts

1. Die plate

The die assembly including the stripper and all bottom elements are mounted on the bottom plate. The bottom plate gives cushioning effect to the die and provides enough space for the tool to be clamped to the press bed. There may be an opening in the base plate, which allows the blank, or slug to fall and clear off from the tool.

It is usually made from D2 tool steel material and is hardened to 60-62 HRC. It provides cutting edge.

When the cutting action is over, the punch withdraws from the die but the stock strip will also move along with the punch. So for next operation, the strip cannot be moved forward. To facilitate this function one plate is fixed above the die plate. This removes the strip from the punch by the unit called stripper. A good stock guide design always allows for staggering the entryway so that the work piece will not snag; a good design also allows for the stock guide to be removable from the die without components having to be disassembled [3].

The die opening has different designs and the design is selected after looking in the requirements and facilities available. The most common die section has straight line and angular clearance. The angular clearance is given in order to allow easy fall of components and slugs. And the land of the die is 1.5t = 4.5 mm die land.

First die block for station one and two the cutting perimeter is 1,374 mm and the shearing force is 1,315,137 N (134 tone).

$T_d = \sqrt[3]{F_{sh}}$ ………………………………………………..………………. 5

Where; T_d = thickness of die plate [cm]

F_{sh} = shear force [tone]

$$T_{D1} = \sqrt[3]{134}$$

$$T_{D1} = 5.1 \text{ cm}$$

Die thickness = 51 + 3 = 54 mm

The die block thickness for punching the three holes at station five with 84.8 mm cutting perimeter and shear force is 61,310 N (6.25 tone)

$$T_{D2} = \sqrt[3]{6.25}$$

$$= 1.85 \text{ cm}$$

Die thickness = 19 + 3 = 22 mm

The die block thickness for punching two holes and cutting of the part at station five with 260.7 mm cutting perimeter and shear force is 188,486 N (19.22 tone)

$$T_{D3} = \sqrt[3]{32.69}$$

$$= 2.7 \text{ cm}$$

Die thickness = 27 + 3 = 30 mm

Deflection and stress calculation

It was assumed that the die block (die plate) to be fixed beam. The recommended deflection of the die block should be less than 0.025mm [2].

$$\text{Deflection } \delta = \frac{FL^3}{192\ EI} \quad \ldots\ldots\ldots 6$$

$$I = \frac{bh^3}{12} \quad \ldots\ldots\ldots 7$$

$$E = 2.1 \times 10^5 \text{ N/mm}^2$$

Where; F = 80% of shearing (cutting) force act on the vertical direction [6].

E = modulus of elasticity

I = moment of inertia of the die block

a) For the first die block

Assumption: - the force is uniformly distributed load

$$F = 0.8 \times 1{,}315{,}137 \text{ N} \quad \ldots\ldots\ldots 8$$

$$= 1{,}052{,}109 \text{ N}$$

L is the distance between the successive screw = 244 mm

Where b = 682 mm and h = 56 mm (the width and the thickness of the die block respectively)

$$I = 8{,}949{,}204 \text{ mm}^4$$

$$\delta = 0.040 \text{ mm}$$

Since the calculated deflection (0.04mm) value is above the recommended deflection (0.025 mm) value it needs to increase the thickness of die block to reduce the deflection. After iteration the appropriate thickness of the die block became 60 mm and the corresponding deflection result obtained met the recommended value.

$$I = 12{,}276{,}000 \text{ mm}^4$$

$$\delta = 0.02 \text{ mm}$$

$$= 0.02 \text{ mm} < 0.025 \text{ mm}$$

$$\sigma = \frac{F}{A} \quad \ldots\ldots\ldots 9$$

$$= \frac{1{,}052{,}109}{682 \times 60}$$

$$= 25.4 \text{ N/mm}^2$$

The stress induced 25.4 N/mm^2 which is much less than the allowable strength 2,200 N/mm^2, hence it is safe design.

b) For the second die block

$$F = 80\% \text{ of cutting force} = 0.8 \times 61{,}310 \text{ N}$$

$$= 49{,}048 \text{ N}$$

L is the distance between the successive screw = 125 mm

Where b = 60 mm, h = 22 mm (the width and the thickness of the die block respectively)

$$I = 53{,}240 \text{ mm}^4$$

$$\delta = 0.044 \text{ mm}$$

Since the calculated deflection (0.044) value is above the recommended deflection (0.025) value it required to increase the thickness of die block to reduce the deflection. After iteration the proper thickness of the die block is 30 mm, hence the deflection will be below the recommended value.

$$I = 135{,}000 \text{ mm}^4$$

$$\delta = 0.017 \text{ mm} < 0.025 \text{ mm}$$

$$\sigma = \frac{49{,}048}{60 \times 30}$$
$$= 27.25 \text{ N/mm}^2$$

The stress induced 27.25 N/mm^2 which is much less than the allowable strength 2,200 N/mm^2, therefore the die block is safe.

c) For the third die block

$$F = 80\% \text{ of cutting force} = 0.8 \times 188{,}486 \text{ N}$$
$$= 150{,}789 \text{ N}$$

L is the distance between the successive screw = 88 mm
Where b = 85 mm, h = 30 mm (the width and the thickness of the die block respectively)

$$I = 191{,}250 \text{ mm}^4$$
$$\delta = 0.013 \text{ mm} < 0.025 \text{ mm}$$
$$\sigma = \frac{150{,}789}{30 \times 85} = 47.4 \times \text{N/mm}^2$$

The stress induced 47.4 N/mm^2 which is much less than the allowable strength 2,200 N/mm^2

2. Bottom plate

The bottom plate gives cushioning effect to the die and provides enough space for the tool to be clamped to the press bed. There may be an opening in the base plate, which allows the blank, or slug to fall and clear off from the tool. The die assembly all bottom elements are mounted on the bottom plate. The material selected for the top plate is St-42.

$$T_b = 1.5 \times T_d \quad \text{……… 10}$$
$$= 1.5 \times 60 \text{ mm} = 90 \text{ mm}$$

Deflection and stress calculation

Bottom plate is considered to be on parallels, the recommended deflection of the die bottom bolster (die shoe) should be less than 0.025 mm by controlling the span between the parallel blocks, or by increasing the bottom bolster thickness in the lower tool. The lower tool can be considered as a simply supported beam with a uniformly distributed load. For the system it is used seven parallel blocks to support the bottom plate.

$$\delta = \frac{5\,FL^3}{354\,EI} \quad \text{……… 11}$$

Where, F = 80% of cutting and forming force

$$F = 0.8 \times 1{,}604{,}132 \text{ N}$$
$$= 1{,}283{,}305 \text{ N}$$

L is the distance between the successive parallel block = 214 mm
Modulus of elasticity (E) = 2.1 x 10^5 N/mm^2
Where b = 1000 mm and h = 90 mm (the width and the thickness of the bottom plate respectively)

$$I = 60{,}750{,}000 \text{ mm}^4$$
$$\delta = 0.014 \text{ mm} < 0.025 \text{ mm}$$
$$\sigma = \frac{1{,}283{,}305}{1000\,x 90}$$
$$= 14.25 \text{ N/mm}^2$$

The stress induced 14.25 N/mm^2 which is much less than the allowable strength 240 N/mm^2.

3. Top plate

The upper working member of the tool is called the top plate. The punch assembly including the punch holder and thrust plate is mounted on the top plate. The tool shank, which locates the whole tool centrally with the press ram, is also screwed into the top plate. Material chosen for the top plate is St-42.

$$T_p = 1.25 \times T_d \quad \text{……… 12}$$
$$= 1.25 \times 60 = 75 \text{ mm}$$

4. Punch plate

The punch is usually fitted to a plate with a light press fit. Punch holder holds all types of cutting and guiding parts to ensure alignment between punch and die made of St-42.

$$T_{ph} = 0.5 \times T_d \quad \text{……… 13}$$
$$= 0.5 \times 60 = 30 \text{ mm}$$

Deflection and stress calculation for top half

It can be considered as a simply supported beam loaded at the center and the deflection is given by;

$$\delta = \frac{FL^3}{48EI} \quad \text{……… 14}$$

F = 80% of cutting and forming force

= 0.8 x 1,604,132 N = 1,283,305 N

Where, L (distance between two successive screws) = 355.5 mm

$E = 2.1 \times 10^5\ N/mm^2$

$I = bh^3/12 = 96{,}468{,}750\ mm^4$

b = 1000 mm and h = (30 mm + 75 mm) = 105 mm (the width and the thickness of the top half respectively)

$\delta = 0.024\ mm < 0.025\ mm$

$$\sigma = \frac{1{,}283{,}305}{1000 \times 105}$$

$$\sigma = 12.2\ N/mm^2$$

The stress induced 12.2 N/mm^2 which is much less than the allowable stress of the material 240 N/mm^2.

5. Guide pillar and guide bush

Guide pillar and guide bush are very important elements in press-tool. Pillar and bush guide the moving and fixed half of the tool in the press and they are also used to ensure accurate alignment between the punches and die. These are made of case hardened St-42. Pillar and bushes are hardened and tempered to 56-58 HRC.

Buckling for guide pillar

Guide pillar material, St-42 with a compressive strength of 330 N/mm^2

$E = 2.1 \times 10^5\ N/mm^2$

Where $L_e = 2l$ for one end fixed and other end free

$l = 153\ mm$

$$I = \frac{\pi D^4}{64} = 2{,}010{,}619\ mm^4 \quad \ldots\ldots\ldots\ldots 15$$

$D = 80\ mm$

$A = 5026.55\ mm^2$

$$S.R = L_e/r_g \quad \ldots\ldots\ldots\ldots 16$$

$$r_g = \sqrt{\frac{I}{A}}$$

$$= 20 \quad \ldots\ldots\ldots\ldots 17$$

S.R = 17.6

$$T.S.R = \left(\frac{L_e}{r_g}\right)_c = \sqrt{\frac{2\pi^2 E}{S_y}} \quad \ldots\ldots\ldots\ldots 18$$

$T.S.R = 112$

Where: - r_g = radius of gyration

S.R = slenderness ratio

T.S.R = transition slenderness ratio

Johnson's equation will be used to calculate the critical buckling load because of the slenderness ratio (S.R) is less than the transition slenderness ratio (T.S.R).

$$F_{cri} = A\left(S_y - \frac{S_y^2}{4\pi^2 E}\left(\frac{L_e}{r_g}\right)^2\right) \quad \ldots\ldots\ldots\ldots 19$$

Where: - S_y= yield compressive strength of the material

$$F_{cri} = 5026.5\left(240 - \frac{(240)^2}{4\pi^2 2.1\text{x}10^5}(17.6)^2\right)$$

$F_{cri} = 1{,}195{,}531\ N$

$F_{cri} = 1{,}195{,}531\ N > 401{,}033\ N$

The applying load is less than the critical load carrying capacity of the guide pillar (1,195,531 N), therefore the structure is safe.

Load per pillar $= \frac{1{,}604{,}132}{4}$

$= 401{,}033\ N/pillar$

$F = 80\ \%$ of 401,033

= 320,826 N/pillar

$$\delta = \frac{Fl}{AE} \quad \ldots\ldots\ldots\ldots 20$$

$\delta = 0.08\ mm$

$$\sigma = \frac{320{,}826}{5026.5}$$

$= 63.8 \ \ \mathrm{N/mm^2}$

The stress induced 63.8 $\mathrm{N/mm^2}$ which is less than the allowable strength 240 $\mathrm{N/mm^2}$ hence, the structure is safe.

6. Punch

A punch is the male member of a press tool to get a component from the strip. The shank should be running fit and the length of the shank should be 1 to 2 mm less than shank hole depth to ensure full contact of the ram face with the top bolster of the tool. The shank clamping screw should be almost at the center of the tapered part of the shank. It is made out of good quality alloy steel called HCHCr (D2) material and hardened to 58-62 HRC. The proper length of a punch has a considerable effect on the overall performance of the die. With too long punches, the compressive stress on them may be excessive, resulting in frequent breakages. The maximum length of a punch may be calculated with the aid of Euler's formula, for punch fixed at one end and guided at the other end the critical force computed by the formula.

$$F_{cri} = \frac{2\pi^2 E I_{min}}{l^2} \quad \ldots\ldots 21$$

If critical force F_{cri} equals punch force, then the maximum length of the punch may be calculated by the following formula;

$$l_{max} = \sqrt{\frac{2\pi^2 E I_{min}}{P}} \quad \ldots\ldots 22$$

$$I_{min} = \frac{\pi D^4}{64}$$

D is the diameter of the punch = 7.5 mm.

$$I_{min} = 155 \ \mathrm{mm^4}$$

$$l_{max} = \sqrt{\frac{2\pi^2 2.1 \times 10^5 \times 155}{28{,}905}}$$

$$l_{max} = 149 \ \mathrm{mm}$$

This is the safe maximum length that can perform without failure.

Buckling for punch

Punch material, D2 with a compressive strength of 2,200 $\mathrm{N/mm^2}$ and modules of elasticity, 2.1 x 105 $\mathrm{N/mm^2}$

Where $L = 2l$ for one end fixed and other end free

$l = 71 \ \mathrm{mm}$

For cylindrical punch 7.5 mm diameter

$$I = \frac{\pi D^4}{64} = 155 \ \mathrm{mm^4}$$

A = 44 mm2

S.R = L_e / r_g

$$r_g = \sqrt{\frac{I}{A}} = 1.87$$

S.R = 75.9

$$T.S.R = \left(\frac{L_e}{r_g}\right)_c = \sqrt{\frac{2\pi^2 E}{S_{yc}}}$$

$$T.S.R = 43.4$$

Euler's equation will be in use to calculate the critical buckling load because the slenderness ratio is greater than the transition slenderness ratio.

$$F_{cri} = \frac{\pi^2 E I}{L^2} \quad \ldots\ldots 23$$

$$F_{cri} = 173{,}576 \ \mathrm{N} > 16{,}990 \ \mathrm{N}$$

The applying load is less than buckling/crippling load; it is safe load.

Assuming the piercing punch as consider as one end is fixed and compressive force is acting on other end. For cutting operation (piercing operation) 80% of cutting force is acting on punch as compressive nature [6].

$$\delta = \frac{Fl}{AE}$$

$$F = 80\% \text{ of } 16{,}990 \ \mathrm{N} = 13{,}592 \ \mathrm{N}$$

$$\delta = 0.078 \ \mathrm{mm} < 0.25 \mathrm{mm}$$

$$\sigma = \frac{F}{A}$$

$$\sigma = 386 \ \mathrm{N/mm^2}$$

The stress induced 389 $\mathrm{N/mm^2}$ which is less than the allowable strength 2,200 $\mathrm{N/mm^2}$.

V. FEM AND ANALYTICAL RESULTS

In the preceding section critical parts of the die is designed by consulting different die hand book, the validation of this design is preferred to perform on software. The critical parts of the die is modeled on solidwork2012 and the simulation has been done on logopress3 software, during the analysis the boundary condition are appropriately given to the meshed model and the material properties are specified as per the selection for each component. The output of the analysis from the simulation is given by counter plot (two selected parts are presented from figure 4 to figure 7) and all the summary of the results are shown in Table 4.

a. Material property

Table 1 Parts of the die and their material property

No	Part name	Type of material	Modules of elasticity [N/mm^2]	Ultimate compressive strength [N/mm^2]	Poisson's ratio υ	Density Kg/ mm^3
1	Piercing and bending punches	High carbon high chromium tool steel (D2)	2.1×10^5	2200	0.394	7600
2	Piercing and bending die	High carbon high chromium tool steel (D2)	2.1×10^5	2200	0.394	7600
3	Upper and bottom plate	Structural steel St-42	2.1×10^5	240	0.3	7800
4	Guide pillar	Structural steel St-42	2.1×10^5	240	0.3	7800

b. Loads

Load for some function elements like top half; bottom plate and die plate are applied on F_z positive direction of magnitude as 80% of cutting force as vertical. And for punches like piercing punch, bending piercing punch, notching punch and blanking punch are applied on F_z positive direction of magnitude as calculated cutting force of that operation as compressive load on surface. And also for guide pillar load applied is on F_x positive direction of magnitude as 10 to 20% of cutting force as thrust load and F_z positive direction of magnitude of 80 to 90% of cutting force as vertical load.

c. Analysis

1. Analysis for the smallest piercing punch

Material: D2; Yield strength 2,200MPa; F (applied load): 80% of the cutting force = 13,592 N

Table 2 Stress plots and resultant displacement for the smaller punch

Part Name	Von Misses Stress		Resultant Displacement	
	Min, N/M^2	Max, N/M^2	Min, mm	Max, mm
Cylindrical punch 7.5 mm diameter	38,071,960.0	400,306,368.0	0	0.08306

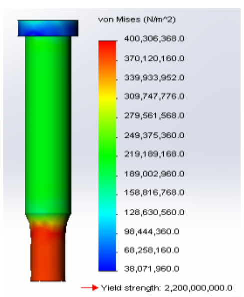


Figure 4 Stress plots of smaller punch

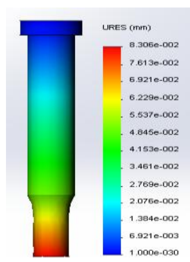


Figure 5 Resultant displacement plot for the smaller punch

2. Analysis for the guiding pillar

Material: St-42; Yield strength 240MPa; F (applied load): 80% of the cutting force = 320,826 N

Table 3 Stress plots and resultant displacement for the guiding pillar

Part Name	Von Misses Stress		Resultant Displacement	
	Min, N/M^2	Max, N/M^2	Min, mm	Max, mm
Guide pillar	1,950,711.0	55,074,736.0	0	0.06307

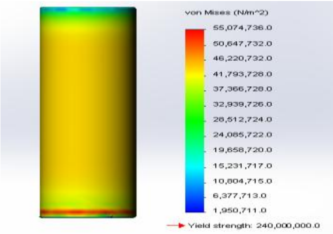


Figure 6 Stress plot of the guiding pillar

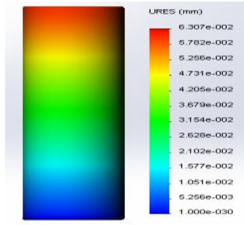


Figure 7 Resultant displacement plot of the guiding pillar

Table 4 FEM simulation and calculated results

SI No	Description	FEM Simulation Results		Calculated Result	
		Deflection [mm]	Stress [MPa]	Deflection [mm]	Stress [MPa]
1	Cylindrical punch 7.5 mm diameter	0.0830	400	0.078	386
2	Cylindrical punch 12.5 mm diameter	0.0420	199	0.062	183
3	Cylindrical punch 15.5 mm diameter	0.0410	201	0.062	184
4	Rectangular piercing punch 1	0.0560	183	0.072	215
5	Rectangular piercing punch 2	0.0127	88	0.012	37
6	Rectangular piercing punch 3	0.0114	68	0.011	33
7	Notching punch 1	0.0680	272	0.036	108
8	Notching punch 2	0.0380	164	0.027	81
9	First die block	0.0014	7	0.020	25
10	Second die block	0.0015	26	0.017	27
11	Third die block	0.0049	30	0.013	47
12	Top plate	0.0053	26	0.024	12
13	Bottom plate	0.0051	21	0.014	14
14	Guide pillar	0.0630	55	0.080	63.8

VI. CONCLUSIONS:

Progressive die is an economical way to form metal components with variety of characteristics, including strength, durability and wear resistance. In this research work, five stage progressive die has been designed for self explosive armors holders manufacturing.

Finite element method (FEM) analysis is done for piercing punches, bending punches, piercing block, bending block, bottom plate, top half plate and pillars. The analytical and FEM result of critical components of the die is sound and the percentage of error is within the acceptable range.

All the results of stress and displacement which were used as a parameter to check the appropriateness of the design of each component shows that it is within the allowable limit. The results obtained from Solidworks simulation, the stress values for all parts are less than the respective yield stress value of the material. So, the designed progressive die parts are safe under the given loading conditions. The tools which are exposed to wear will work in optimum condition by satisfying structural stability; furthermore parts which are not directly in contact with the blank material give their required function without any difficulty of structural integrity and stability. The deflections of all the parts during operation are kept below 0.025mm as per the recommendation of die manufacturer.

The total tonnage required to manufacture explosive reactive armor holder is 213 tones including 30% of factor of safety. And the existing hydraulic press machine, in Bishoftu motorization industry has the capacity of 250 tones, which meets the requirement of press tonnage capacity to manufacture the part. Hence, the company can use all the results and order the die to be manufactured as per the given dimension to manufacture the explosive reactive armor holder within the company by attaching the die to the press machine; by making use of the manufactured products the company can realize its plan of covering Tank 55 model and Tank 62 model with explosive reactive armor.

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