Design, Fabrication and Manufacturing of 100 Ton Hydraulic Press to Perform Equal Channel Angular Pressing (ECAP)

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Abstract-There are different mechanical presses used to deform or press the material through dies to convert into useful product by applying different conditions like temperature, pressure, speed of ram etc. These material deformation techniques not only used to produce finished products but also to increase the strength of the material by introducing severe plastic deformation. Equal channel angular pressing (ECAP) is a technique used to increase the strength of materials by introducing severe plastic deformation through grains refinement. The ECAP die consisting of two channels intersecting at 90 degree was designed and manufactured to perform angular extrusion. The load was calculated through mathematical modelling. A hydraulic press equipped with conventional temperature control furnace, sensor based limit switches, pressure controlled mechanism and with variable speed control was designed, fabricated and manufactured at UET Taxila. The material used for the fabrication purposes is mild steel. The major designing parameters included stroke length, maximum load, pressure, cylinder bore, sealing mechanism and volume flow rate of working fluid. The main parts of the hydraulic press consist of piston and cylinder arrangement, structure or frame, press stand and hydraulic circuit. The press was tested initially for its leakage and then test was performed on Teflon and Nylon materials at 2 tons of pressure. Later on the aerospace grade aluminum alloy 6061 was pressed through ECAP die at a speed of 9mm/sec.

Keywords-Hydraulic Press, Pump, Pressure, Cylinder Bore, Speeds of Ram, Hydraulic Circuit.

I. INTRODUCTION

In the history of science and engineering, the development of engineering equipment is progressing and better machines are being developed with high measures of safety and precautions. There are different materials deforming techniques (rolling, forging, extrusion, forming, wire drawing etc.) used to produce different kinds of products, extrusion is one of these. Extrusion process is very simple in which specimen is pressed through a die with the help of punch to produce a continuous length with constant or variable cross-section depending upon the shape and size of the die. Due to the importance of angular extrusion to introduce severe plastic deformation for grain refinement new, better and electronically controlled presses were developed [i].

To push, pull, rotate or to thrust the material through the dies more efficient and suitable presses have been developed and manufactured [ii]. As pressing of material through presses seem very simple and because of that highly engineering presses were not designed in the past [iii]. Presses are the pressure exerting mechanical machines used for different purposes [iv, v]. The presses can be categorized into following three main types as:

- Hydraulic presses actuates on the principles of hydrostatic pressure.
- Screw presses actuate due to power screws to transmit power and
- Mechanical presses in kinematic elements linkage is used to transmit power[vi-viii].

In hydraulic press fluid is used under pressure to generate force, amplification and transmission. The liquid system shows good characteristics of solid and offers rigid and positive power transmission and amplification. The amplification took place when a small piston transfers fluid to a large piston under high pressure in a simple application. The large amount of energy can be easily transferred practically by amplification also it has a very low inertial effect.

Hydraulic press comprises a pump which generates power for the fluid and this power of fluid is transferred through hydraulic pipes, control valves, connectors and finally to the hydraulic motor which transforms hydraulic energy into mechanical energy or work at the point of interest[ix, x].

Hydraulic presses provide more positive actuation against the input pressure, over other types of presses, used to accurately control the force and pressure that is available during the whole working stroke of the ram [xi]. The hydraulic presses are very useful and effective when very large magnitude of force is required to process the material [xii-xiii]. The hydraulic press is much appreciated device in laboratories and workshops particularly for material deformation, testing and press fitting operations. To carry out equal channel angular pressing experimentation, it was decided to design, fabricate, and to manufacture a hydraulic press with a capacity of 100 tons using locally available material. It not only saved the money, if imported from abroad, but enhanced technical knowledge about press manufacturing, designing and fabrication [xiv]. In this research work a special purpose hydraulic press is designed and fabricated. ECAP experimental setup was also built and experiments proved strength enhancements of the material.

II. Design Methodology

Hydraulic power systems were designed according to the requirements of ECAP. The main issue of designing such system was to rearranging the required performance parameters of the system into hydraulic pressure system, volume flow rate and then comparing these performance parameters to the system to endure operation. The principal designing parameters included the piston stroke, maximum load, cylinder bore, volume flow rate of the working fluid and system pressure. The important designing components included hydraulic cylinder, hydraulic circuit and main structure of the system known as frame.

A. *Press Load Calculations*

The pressing load was calculated for ASTM AISI H13 tool steel that is being used in ECAP die manufacturing. the flow stress of the material is 35 MPa and the surface friction or tresca friction is considered as 0.3, because a very high contact pressure developed between die walls and work piece, when huge stock is severely deformed. ECAP die is composed of two channels and these channels are divided into three regimes 1, 2, and 3 for calculating the speed and load as shown in Fig. 1.

1) Regime 1-2

The schematic diagram is shown in Fig. 2, in which velocity is determined from the initial position up to the regime 2. The specimen, which is pressed through the ECAP die with the help of plunger at a constant speed, is inserted in the die inlet channel. The plunger pressed the specimen through ECAP die inlet channel until it reached its bottom extreme position and then entered into the second regime. The initial velocity was considered Vo.

$V_1 = V_o, V_{1N} = V_{2N} = V_0, V_{T1} = 0$

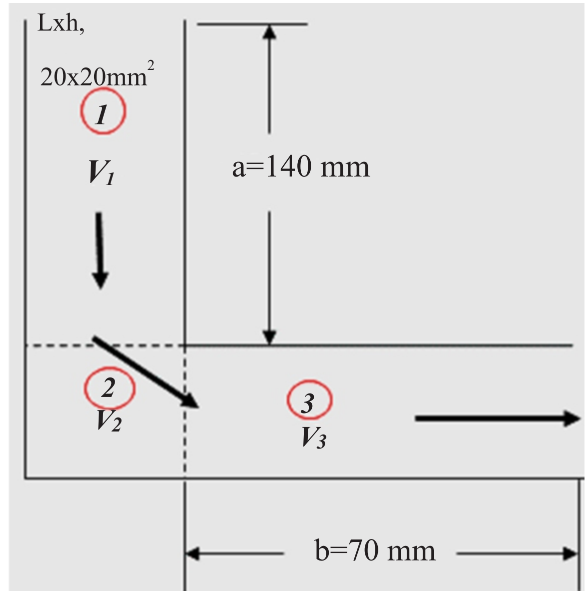

Fig. 1. Schematic diagram of die regimes

$$\Delta V_{T(1-2)} = |V_{T1}| + |V_{T2}| = V_0 \quad (1)$$

Where V_T = tangential component when and V_N = Normal component

$$Cos\ 45^0 = \frac{V_0}{V_2} = \frac{1}{\sqrt{2}}, V_2 = \sqrt{2}V_0 \quad (2)$$

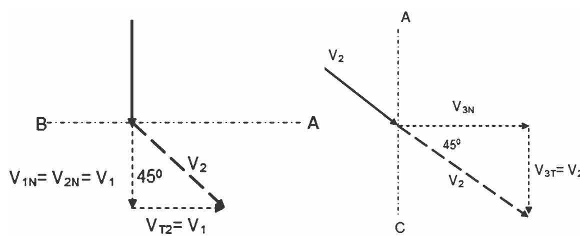

Fig. 2. Die regimes (a) 1-2 regime (b) 2-3 Regime

2) Regime 2-3

$V_2 = V_{2N} = V_{3N}$ = Normal component of resultant velocity.

$$Cos\ 45^0 = \frac{V_3}{V_2} = \frac{1}{\sqrt{2}} => V_3 = \frac{V_2}{\sqrt{2}}$$

$$V_3 = \frac{\sqrt{2}V_o}{\sqrt{2}} = V_o \quad (3)$$

Let

$\overline{W}_i$ = Deformation energy

$\overline{W}_f$ = friction energy

$\overline{W}_e$ = Equivalent energy

$\overline{m}$ = surface friction

$$\overline{W}_i = \frac{\sigma_o}{\sqrt{3}} h V_0 \left(1+\sqrt{2}\right) \quad (4)$$

$$\overline{W}_f = \frac{\overline{m}}{\sqrt{3}}\sigma_0\left[(V_0 a) + 4\sqrt{2}V_0(2h) + 4(V_0 b)\right] \quad (5)$$

$$\overline{W}_e = \frac{\sigma_0 V_0}{\sqrt{3}} L\left[\left(1+\sqrt{2}\right)h + \overline{m}(4a + 2\sqrt{2}h + 4b\right] \quad (6)$$

where

$$\overline{W}_e = \overline{W}_i + \overline{W}_f \quad (7)$$

The force applied by the press on the specimen is evaluated as:

$$FV_0 = \overline{W}_e,$$

$$F = \frac{\sigma_0}{\sqrt{3}} L\left[\left(1+\sqrt{2}\right)h + \overline{m}(4a + 2\sqrt{2}h + 4b\right] \quad (8)$$

Now taking known values of σ_o, L, H, a, b and $\overline{m}$ substituting in equation 8, the pressing load is equal to 13 Tones.

B. Design of Hydraulic Cylinder

The shape of hydraulic cylinder is of tube-shaped in which piston slides due to the hydraulic fluid pumped into it with hydraulic pump as shown in Fig. 3.. The design requirements of hydraulic cylinder included end cover plate, minimum wall thickness of the cylinder, thickness of flange and specification, sizes and number of bolts [xv].

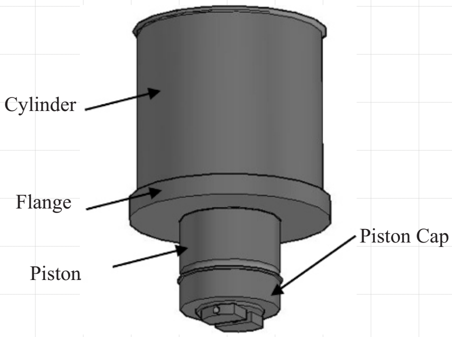

Fig. 3 . Isometric view of cylinder and piston

The determination of cylinder area, minimum wall thickness and cylinder bore depend upon required output force of hydraulic cylinder and available hydraulic pressure.

Wall thickness 't' of hydraulic cylinder was computed using equation 9 which was equal to 22.8 mm.

$$t = r_i\left[\sqrt{\frac{\sigma_t}{(\sigma_t - 2P)}} - 1\right] \quad (9)$$

where

r_i = Internal radius of cylinder = 0.7 m

P = Internal fluid pressure = 50 Mpa

σ_t = Tangential stress = 480x10^6 Mpa

Equation 10 was used to determine thickness 'T' in mm of the end cover plate which is fixed at the top of the cylinder and was subjected by a uniformly distributed internal pressure.

$$T = KD\sqrt{\frac{P}{\sigma_t}} \quad (10)$$

Where:

D = Diameter of end cover plate (m)

K = Coefficient depending upon the material of plate

P = Internal fluid pressure (Mpa)

σ_t = Design stress of the cover plate (480 Mpa)

The thickness 'T' of the end cover plate was found equal to 40.5 mm

C. Design of Cylinder Flange

The cylinder flange may fail due to pressure exerting at it in tensile nature [xvi-xvii] . In designing the cylinder flange, its minimum thickness 't_f' is to be determined using bending theory. Cylinder flange was an essential part to place at the top of cylinder for tightening purpose. Two types of forces were very important for designing point of view; one was the pressure of fluid and second was its tendency to detach the flange due to sealing and it was restricted by the stress induced in the bolts [xviii]. This force can be determined by equation 11 and its value is 6.5x10^4 N.

$$F = \frac{\pi D_s^2}{4} P \quad (11)$$

where:

D_s = outside diameter of seal = 175 mm

D. Determination of Flange Thickness

Applying bending theory, the thickness of flange was obtained along the weakest section A-A as shown inFig. 4.

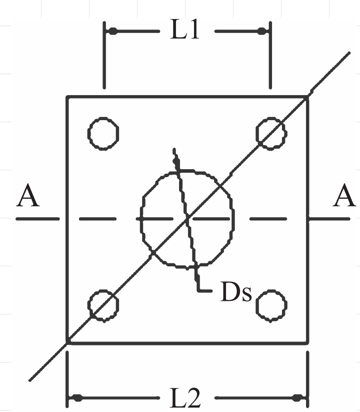

Fig. 4. Sketch of square flange

L1 is the distance between holes centers and L2 is the overall length of cover plate. The bending is developed due to fluid pressure inside the cylinder and the forces in the bolts. The equation 12 was used to determine the flange thickness which was found equal to 60 mm.

$$T_f = t_f = \frac{6M}{b\tau} \qquad (12)$$

where:
b=Width off langeat section A-A 40 mm.
τ= Shear stress of flange material 480 Mpa.
M= Resultant bending moment 6512.5 N-m.

E. Design of piston and rod

The piston rod was influenced by a number of factors such as the force acted upon due to compression, fixing condition of cylinder itself, the stroke length over which the load was to be applied and strength of piston rod. So the column size and dimensions of the piston rod should sustain these loading conditions. The piston rod is also aligned with the center line of the cylinder bore.

Keeping in view the above mentioned parameters, the piston rod was selected 95 mm in diameter.

F. Selection of Seals

In hydraulic system sealing is a very critical issue. The fluid in hydraulic system is compressed at very high pressure, the sealing plays a vital role and is very important. Under different operating conditions of speed and pressure, seals are used to avoid any kind of leakages in the system. Different sealing mechanisms are used in hydraulic system for static seal, the groove and ring principle is used to make sealing affective. The groove dimension is based on the compression of the O-ring in one direction and expansion to the other direction when compressed. Under this principle, the O-ring is compressed 15 -30% in one direction and equal to 70-80% of the free cross-sectional diameter. For this purpose the groove dimension of 6 mm x 5 mm was identified for the sealing purpose.

G. Frame Design

The frame provides a rigid support for the hydraulic unit placed over it. The units and all other related parts were mounted on it during all working environments and conditions. The column of the frame is directly under the condition of tensile loading. So columns are designed using column theory. The base plate of the system on which sample is placed and pressed is under the action of pure bending. The lower and upper plates provide a direct point of contact with the sample being compressed. Due to equal and opposite couple in the same plane, these are under pure bending stress. So the design of these plates is based for the determination of maximum bending moment (M) and the larges value of shear force (V) applying beam theory. The value of maximum bending moment was determined equal to 7.5×10^4 N-m and largest value of shear force was found equal to 32×10^4 N.

The section modulus of the plates was determined using values of shear force (V) and bending moment (M). The minimum thickness (t) of the plates was determined to be 40 mm using equation 13.

$$t = \sqrt{\frac{(6M)}{\sigma b}} \qquad (13)$$

Where;
M= Maximum bending moment, 7.5×10^4 N-m;
$b = 600 \times 10^{-3}$ m;
$\sigma = 480 \times 10^6$ PMa

H. Assembling of parts

The maximum fluid discharge including a factor of frictional loss was determined equal to 59.5×10^6 N/m^2. A four stage solenoid actuator was attached with the pumping system, the pressure can be changed with the help of this solenoid actuator.

Two MS plates 435 x 435 x 40 mm^3 were purchased; machined and converted into final required dimensions. Four MS rods 60mm diameter and length of 1000 mm were purchased, machined and fixed with the lower and upper plates. The frame for the system was fabricated with MS angle iron of 50 x 50 x 4 mm. MS pipe of Φ160 mm with Φ100 mm internal diameter was purchased, bored and lapped to Φ120 mm on the Lathe machine.

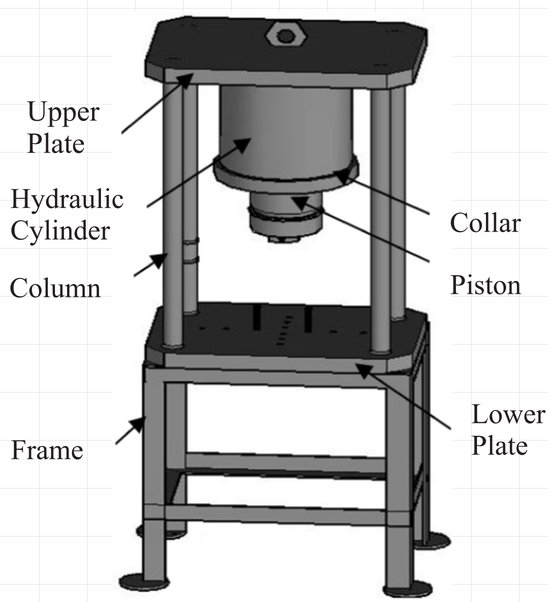

Fig. 5. Isometric view of Hydraulic press with bed

The piston and cylinder were assembled and welded with the top plate. Two limits switches were also fixed with one of the vertical columns to control the motion. Two house pipes were also fitted with the cylinder for the flow of liquid. The complete assembly of the hydraulic is shown inFig. 5.

III. TESTING PERFORMANCE

The testing of engineering components/system is a normal routine after their manufacturing. Also it is part of the design procedure to test the components or system for their performance. Different kinds of tests were performed to check strength, leakage, quality, repeatability, to see that it satisfied its functional requirements. The leakage test is very important for hydraulic presses. The test was started by priming the pump and then fluid was pumped without any load for at least three hours. The hydraulic press then was tested by applying a load of 15 kN on two open coiled helical springs having spring rate 10 N/mm. The springs were arranged in parallel between plunger and base plate. The springs were compressed axially for a length of 70 mm. The load was applied for two hours to test leakage and no leakage was observed.

The accurate and correct working of equipment depends upon its fine tuning and calibration performed according to some standard. There are two different techniques used for the calibration of hydraulic presses; one is hollow load cell and second is thread bar. This hydraulic press is calibrated using thread bar method according to the ISO standard 7500-1. With the help of thread bar method, different accessories and their influence on uncertainty of calibration were analyzed. A load cell of 100 tons was used for calibration. The calibration was performed with loading force capacity up to 200 MPa and the uncertainty was found only 0.2% of the load applied.

IV. NUMERICAL SIMULATION

Numerical simulation of ECAP was performed on three dimensional specimens made from Nylon, Teflon and Al-6061 alloy. Teflon and Nylon were selected due to their high elastic behavior for the verification of mathematical model. After verification of the model it was applied on Al-6061 and shear strain was determined at different nodes along major and minor axis of the deformed specimen. The ECAP process was modeled and simulated using ABAQUS/Explicit™ as shown in Fig. 6. Initially the geometric model with the dimensions of 20x20x120 mm^3 was modeled. Flow behaviour of material and orientation in the axis was observed by numerical simulation. All degrees of freedom of the die were constrained whereas the plunger had been given a velocity V_z = 0.5 m/sec in negative y-direction with the constraints along X and Z axis. The billet was meshed with linear hexahedral element type C3D8R having 15977 number of elements, total nodes of 18522, an 8-node linear brick, reduced integration, hourglass control element with approximate size of 0.1 mm. Die was considered as rigid body, meshed with discrete rigid element R3D3 with 0.5 element size, a 3-node 3-D rigid triangular facet. The boundary conditions for die were “Encaster”. The plunger was meshed with discrete rigid element R3D4, A 4-node 3-D bilinear rigid quadrilateral just to increase the computation speed. The change in shape of the specimen and formation of ellipse was due to the rotation of axis, when pressed through ECAP die with the help of hydraulic press.

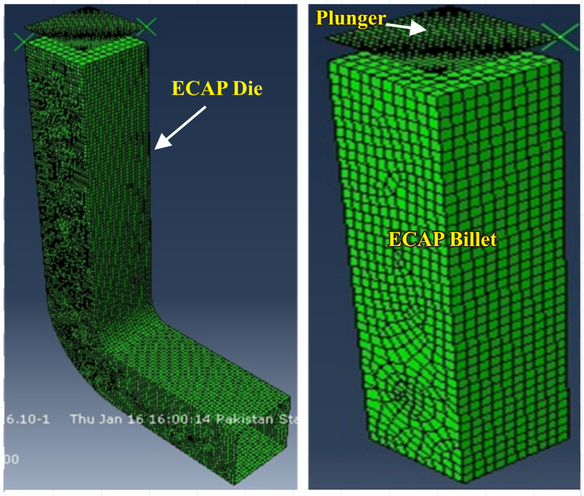

Fig. 6. ECAP specimen with die and plunger

V. EXPERIMENTAL RESULTS

After fabrication of the hydraulic press, ECAP tests were performed successfully. In this section, a few of the outcomes of this experimental set up are presented.

A. Mechanical Characterization

The tensile strength of Al-6061 before and after ECAP process was evaluated on a material testing system of 100 kN (MTS-810). The dog bone specimens were prepared according to ASTM standard E-8. The Table I shows the percentage increase in mechanical strength of Al-6061 after single pass.

Al-6061 alloy was pressed through ECAP for its mechanical characterization. Engineering stress-strain curves of as-received and ECAP specimens of Al-6061 material are shown in Fig. 7 and Table I. The curves reveals that there is 15% increase in yield strength and 39% ultimate tensile strength after performing ECAP.

TABLE I
STRENGTH IMPROVEMENT BY ECAP

Yield Strength (σ_y) (MPa) (Al-6061)		%age increase in σ_y	Ultimate Tensile Strength (σ_u) MPa (Al-6061)		%age increase in σ_u
As-is	ECAP		As-is	ECAP	
270	310	15%	310	430	39%

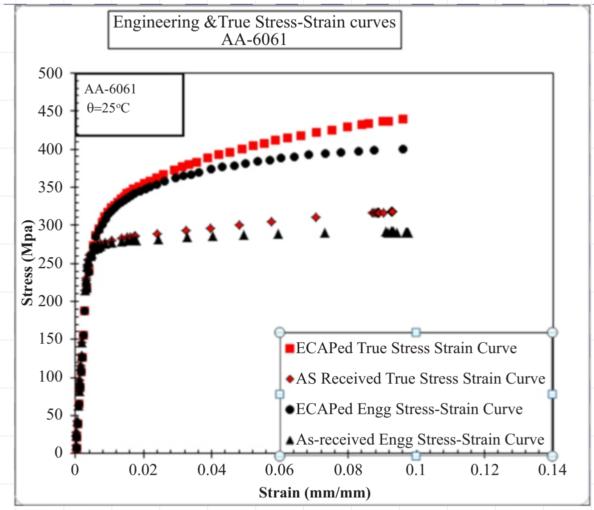

Fig. 7. Eng. and true Stress-strain curves of Al-6061

VI. Conclusion

A 100-ton hydraulic press was designed, fabricated, manufactured, and calibrated. The press was tested to ensure adaptability and conformability. The hydraulic press was found to be satisfactory at a test load of 40ton. The press was also tested at different pressures starting from 20 Mpa to 200 Mpa. Any leakage or drawback was not found during operation. This hydraulic press is now available in Fracture Mechanics lab of the Mechanical Engineering Department and is being used by different research groups.

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