CROSS DIES FORGING
A NEW METHOD TO REDUCE FORGING FORCE & PRICE UP TO 80 %

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Abstract— Purpose of this article was to introduce a new method of forging which is called “Cross Die Forging”. In this method, the required force (load) is reduced to the greatest possible degree through elimination of flash channel; however, this would also decrease the positive effect of flash channel, namely filling the gaps and pores within the mold. Cross die forging procedure provides a way for providing a better preform design which ensures that the mold is filled without allowing the material to enter the flash channel.

This method has been invented based on the need to decrease the production costs and to use lower tonnage pressing devices for production of heavy parts. This method is an economical method only for parts that:

A)Has at least one plane of symmetry and the two ends that are perpendicular to the symmetry plane are flat

B)Has a weight that makes it impossible to be manufactured by rolling or roll forging processes. Examples of such parts are valve’s body, T-junctions, etc.

Keywords—Cross die forging, Close dies forging, Open dies forging, Heavy part forging and reduce forging force

I. INTRODUCTION

Forging is a manufacturing process in which the part undergoes plastic deformation under compressive load and temperature. This method not only deforms the part, but also improves the mechanical properties due to smaller grain size in this case.[4]

Generally, forging process is classified into closed and open die forging. Tools and shape of the die used in open forging process do not match the final shape of the product; while, in closed die forging, shape of the die is almost the same as the final shape of the part; and to give the part its final shape, various types of preform molds are used in a step by step approach.[4]

One of the conventional methods used to reduce cost of production is parting-off method in which the preform is turned into a profile whose shape is almost the same as final shape of the part using rolling process. Then, after the cutting process, the resulting part will be used as the preform for the closed die. But, producing the preform for heavy parts by parting-off method requires large force as well as rollers with large diameter which makes it practically impossible to use this method for production of the preform.[3]

In cross method, production of preform is performed by a shaped die1 during a step by step procedure with controlled loading which makes it possible to produce heavy parts.[5],[6]

On the other hand, in the closed die forging method, a large force is needed to form (shape) heavy parts which requires application of high tonnage pressing device.[7]

Due to elimination of flash channel and providing appropriate preform design, as mentioned above, in cross die method, which is a combination of closed and open die approaches, a pressing device with lower tonnage is needed compared to closed die method, for the same weight. However, the part forged by cross method would be in semi-raw state2 with higher machining costs than closed die method; but, for small production volume, application of this method would be economical.[2]

II. THEORETICAL FRAME WORK

Current study aims to propose a new method called cross forging method. In this method, the parting line in molds is considered to be the plane of symmetry for the part and molds are assumed to be open-ended, in order to decrease pressure inside the mold. This greatly prevents the materials from entering the flash channel and causes the materials to flow in paths perpendicular to each other. However, this condition mitigates the positive effect of flash channels, i.e. filling the gaps and spaces in the molds. But, this method also greatly reduces the required deformation load.[1]

In following, percent decrease in the required load is calculated using the available relations: [3]

$$F_{f_l} = 6.3 \times A^2{}_{f_l} \times \sqrt{\frac{1}{L_{f_l} \times V_{f_l}}} \quad (1)$$

$$F_{f_o} = 6.3 \times A^2{}_{f_o} \times (1+r) \times \sqrt{\frac{1}{L_{f_o} \times V_{f_o}}} \quad (2)$$

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$$F_T = F_{f_l} + F_{f_o}$$

$$S = \frac{(F_T - F_{f_l})}{F_T} \times 100 = \frac{(F_{f_l} + F_{fo} - F_{f_l})}{(F_{fl} + F_{fo})} \times 100 = \frac{F_{f_o}}{F_{f_l} + F_{fo}} \times 100$$

$$= \frac{1}{1 + \dfrac{F_{fl}}{F_{fo}}} \times 100 = \frac{1}{1 + \underbrace{\left(\dfrac{A_{fl}}{A_{fo}}\right)^2 \times \left(\dfrac{1}{1+r}\right) \times \sqrt{\dfrac{L_{fo} \times V_{fo}}{L_{fl} \times V_{fl}}}}_{K}} \times 100 = \frac{1}{1+k} \times 100$$

$$S = \frac{1}{1+k} \times 100$$

$r = \dfrac{w}{t} = 3 + 1.2 \times e^{-1.09W}$ (4) [3]],[8]Neuberger &Mockel

$t = 0.89 \times \sqrt{W} - 0.017 \times W + 1.13$ (5) [3],[9]

Now, value of S is calculated for cylinders with diameter and length equal to D and L, respectively, positioned horizontally inside the closed and cross dies:

$$V_{fo} = \frac{\pi \times D^2}{4} \times L \qquad (6)$$

$$V_{fl} = [(L + 2 \times w) \times w \times t] \times 2 + 2 \times D \times w \times t \qquad (7)$$

$$L_{fo} = L \qquad L_{fl} = L + 2 \times w \qquad (8),(9)$$

$$A_{fo} = D \times L \qquad (10)$$

$$A_{fl} = [(L + 2 \times w) \times w] \times 2 + 2 \times D \times w \qquad (11)$$

$$V_{fo} = \frac{\pi \times D^2}{4} \times L \qquad (12)$$

$$V_{fl} = [(L + 2 \times w) \times w \times t] \times 2 + 2 \times D \times w \times t \qquad (13)$$

$$L_{fo} = L \qquad L_{fl} = L + 2 \times w \qquad (14),(15)$$

$$A_{fo} = D \times L \qquad (16)$$

$$A_{fl} = [(L + 2 \times w) \times w] \times 2 + 2 \times D \times w \qquad (17)$$

Table 1.Values of S, F_0 and F_T for cylinders with different values of D and L (L=1.8×D)

Row	D(mm)	L(mm)	W(kg)	t(mm)	w(mm)	k	S	F_T(N)	F_o(N)	F_l(N)
1	50	90	1.4	2.2	7.0	0.311	76.3	317508	136462	181046
2	70	126	3.8	2.8	8.5	0.270	78.7	525527	252052	273475
3	90	162	8.1	3.5	10.6	0.262	79.2	850049	414708	435340
4	110	198	14.8	4.3	12.9	0.262	79.2	1268492	619475	649017
5	130	234	24.4	5.1	15.3	0.264	79.1	1777163	865217	911946
6	150	270	37.4	5.9	17.8	0.266	79.0	2375592	1151916	1223676
7	170	306	54.5	6.8	20.3	0.267	78.9	3061889	1479572	1582317
8	190	342	76.1	7.6	22.8	0.268	78.8	3832745	1848185	1984560
9	210	378	102.7	8.4	25.2	0.269	78.8	4683498	2257755	2425743
10	230	414	135.0	9.2	27.5	0.268	78.9	5608187	2708282	2899905

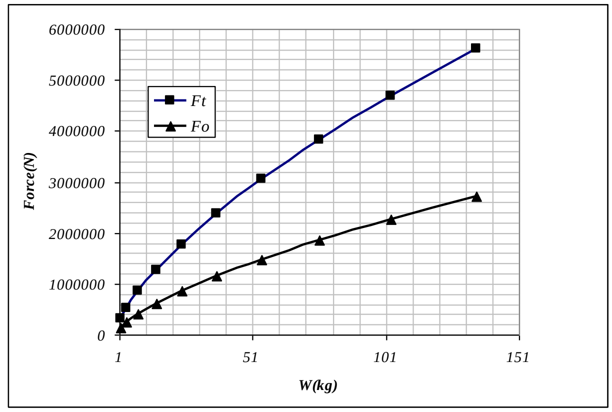


Fig.1Diagram Comparing The Required Forging Load For Parts With Different Weights Forged By Closed Dies (FT) And Cross (F0).

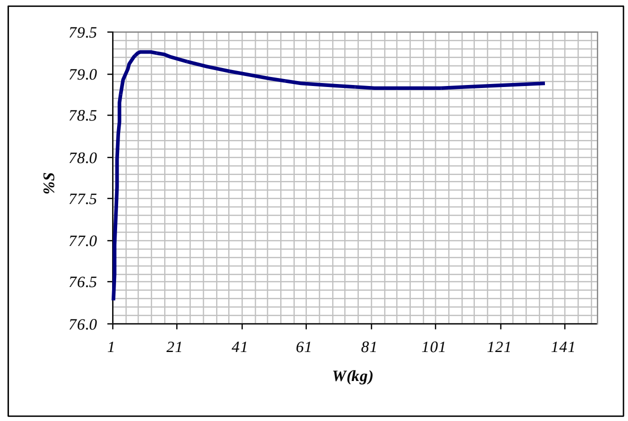


Fig. 2 Showing The Percent Decrease In The Required Forging Load (%S) For Parts With Different Weights Forged By Cross Dies (F0)

As evident in the diagrams, when the pressure inside the mold decreases to the extent that material flows towards open ends of the mold instead of flowing through the flash channel, the required forging force (load) also decreases. The required forging load increases with increase in weight of the part. Thus, if all the gaps and pores within the mold are filled before material enters the flash channel, then there is no need to increase the pressure inside the mold through designing the flash channel. However, the main problem here is to fill the mold by the preform.

In cross forging method, preform is designed so that it completely fills the mold, and also it prevents materials from entering the flash channel. In this method, all the preforms are manufactures by profile method with two open molds using hammer or pressing device. Then, after being cooled, they are cut and used as the preform. The main goal is to produce a profile that can be used as the preform, when rotated 90 degrees around y axis.

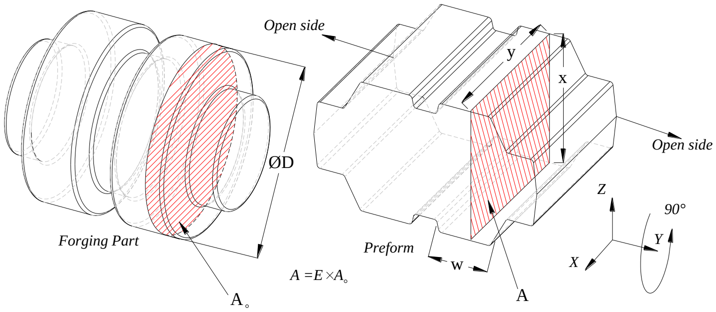


Fig. 3Each Quadrilateral Section In The Profile Must Fill The Circular Sections In The Mold Without Formation Of Any Flash. In Order To Reduce The Pressure Inside The Mold, Both Ends Of The Mold Are Assumed To Be Open.

Now, since every each quadrilateral section in profile must fill the circular sections in the mold while producing least amount of flash, this question is raised: what kind of quadrilateral with what dimension is able to fill the molds with smallest possible force? To answer this question, shaped molds with internal diameter of 50-200 mm and anvil's width equal to 30-200 mm (Fig.4) were tested to be used as quadrilateral sections of different sizes according to table 2.

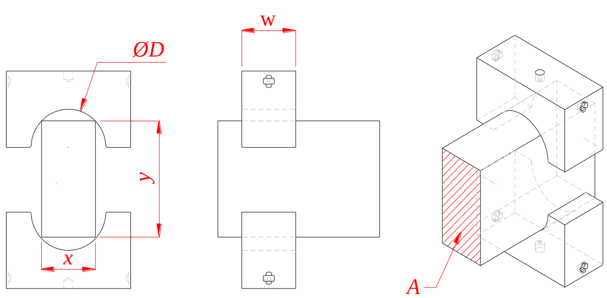


Fig. 4SchematicDiagram Related To Testing The Cross Molds

	$A=E_m \times A_0$	Row	X(mm)	Y(mm)	Accepted	Description	Force (N)
E_4 .III	1.4	1	40	68.69	**Y** .IV **ES**		
	Y/X ≤ 2.8 .A	2	35	78.5	*Yes*		
	$X < D_n$	3	25	109.9	*No*		
D_1	*50 mm²*	4	20	137.4	*No*		
	W_1=100 mm	5	10	274.8	*No*		
Material	*AISI 1018*	6	0	-	-		
Die Temperature	*300 c°*	7	-	-	-		
Work piece Temperature	*1100 c°*	8	-	-	-		
Press	***Hydruali .B c, 25mm/s***	9	-	-	-		
Friction	*0.3*	10	-	-	-		
		11	-	-	-		

E_m: Escape confection D_n: Diameter of Round Bar (mm) A: Area of Square bar (mm²) A_0: Area of Round Bar (mm²)

Table 2.Dimensions Of Quadrilateral Sections Used To Fill The Shaped Molds With Internal Diameter Of 150 Mm And Width Of 100 Mm. It Must Be Noted In This Table, Em=1.4. For Each EmAnd D And Different Anvil Width, W, Quadrilaterals With Different Sizes Were Tested By Considering The Size Limitations Mentioned In Left Side Of The Table.

1300 tests were performed on steel AIAI 1018, which is considered among the low-carbon steel, according to the following conditions:

Mold material was considered to be L6 and temperatures of die and work piece were set at 1100 and 300 degrees Celsius, respectively. Friction coefficient between die and work piece was considered to be 0.3. Also, a hydraulic pressing device has been used with ram speed of 25 mm/s.

Row	W(m)	D(mm²)	A_o(mm²)	E	X	Y	K	F(N)
1	30	50	1963	1.7	40	83	2.1	2.85E+05
2	30	60	2826	1.5	50	85	1.7	2.97E+05
3	30	70	3847	1.6	55	112	2	2.59E+05
4	30	80	5024	1.6	65	124	1.9	4.38E+05
5	30	90	6359	1.4	80	111	1.4	4.36E+05
6	30	100	7850	1.4	90	122	1.4	5.04E+05
7	30	150	17663	1.4	135	183	1.4	7.33E+05
8	30	200	31400	1.4	185	238	1.3	1.05E+06
9	60	50	1963	1.6	40	79	2	5.30E+05
10	60	60	2826	1.6	50	90	1.8	6.40E+05
11	60	70	3847	1.6	60	103	1.7	7.46E+05
12	60	80	5024	1.5	70	108	1.5	8.02E+05
13	60	90	6359	1.5	80	119	1.5	9.04E+05
14	60	100	7850	1.5	90	131	1.5	1.01E+06
15	60	150	17663	1.5	135	196	1.5	1.50E+06
16	60	200	31400	1.4	190	231	1.2	1.99E+06
17	100	50	1963	1.5	40	74	1.8	9.12E+05
18	100	60	2826	1.5	50	85	1.7	1.06E+06
19	100	70	3847	1.6	55	112	2	1.23E+06
20	100	80	5024	1.5	65	116	1.8	1.34E+06
21	100	90	6359	1.6	75	136	1.8	1.56E+06
22	100	100	7850	1.6	85	148	1.7	1.75E+06
23	100	150	17663	1.6	135	209	1.6	2.62E+06
24	100	200	31400	1.7	180	297	1.65	2.83E+06
25	150	50	1963	1.5	40	74	1.8	1.50E+06

Table 3.By Knowing Values Of W And D Or A0, Dimensions Of A Quadrilateral That Could Fully Fill The Shaped Open Die With Diameter Of D (Without Formation Of Flash) And Minimum Required Force Is Shown In The Above Table. (A=A0×E, K=Y/X, F=Fz(Forging Force))

This Table Holds True For Weights Within Range Of 1.5 Kg ≤W≤100 Kg; All The Measures Obtained For The Dimensions Are Related To Hot Dimensions(Smulatied With MSC.Superforge Software)

Now, it is evident that increasing the anvil's width, considering that profile diameter is fixed, decreases E and also increases the required force. Moreover, during the tests, we found out that for each value of E, W and D, if a quadrilateral with dimensions of x1 and y1 fills a profile with diameter D, it would also fill a quadrilateral of dimensions x2 and y2, provided that y2≤y1.

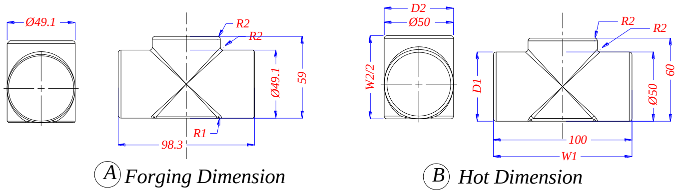


Fig. 5A- Forging Dimensions, B- Hot Dimensions

Assume that there is a forging part according to Fig.5-A with approximate weigh of 1.8 Kg and made of AISI 1018 for which we want to determine the preform to be used in cross forging method. First, hot dimensions of the part are calculated (Fig.5-B). Then, dimensions are calculated according to table 3, considering the fact that there must be quadrilateral with dimensions of X, Y for every circular section with cross section areas of A and width of W:

$W1=100$, $D1=50$ $\rightarrow$ $X1=40$, $Y1=73.6 \rightarrow F1=9.12\times10^5$ N (18)
$W2/2=60 \rightarrow W2=120$, $D2=50$ $\rightarrow W'2=100$, $D2=50 \rightarrow X'=40, Y'=73.6$ $\rightarrow$ $F'=9.12\times10^5$ N (19)
$W''2=150$, $D2=50 \rightarrow X''=40, Y''=73.6 \rightarrow F''=15\times10^5$ N

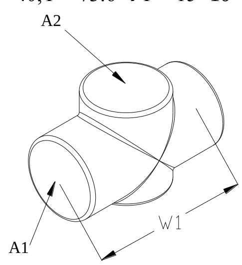


Fig. 5.1

$\rightarrow$ $X2=40, Y2=73.6$ $F2=(F'+F'')/2=12.06\times10^5$N (20)

$FT=F1+F2 =9.12\times10^5 + 12.06\times10^5=2.11\times10^6$ N (21)

$40\times73.6\times t_1 = 3.14\times50^2/4\times100+33382 \rightarrow$ $t_1=78$(22)

$40\times73.6\times(t_2-40) = 3.14\times50^2/4\times10 \rightarrow$ $t_2 = 46$ (23)

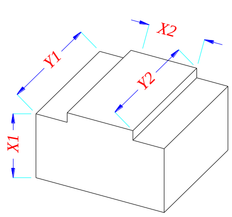


Fig. 5.2 PartIn Its Raw Preform Shape

$40\times73.6\times t_1 = 3.14\times50^2/4\times100+33382 \rightarrow$ $t_1=78$(24)
$40\times73.6\times(t_2-40) = 3.14\times50^2/4\times10 \rightarrow$ $t_2 = 46$ (25)

If $y1\leq y2$, y1 is chosen as width of the profile and x1 is calculated according to E ratio; and dimensions of the profile is modified in this way. But if $y2\leq y1$, y2 is considered as width of the profile, and x2 is calculated according to E ratio.

By comparing the force obtained from equation 1 and Fig.9.1, it is evident that the required force for producing the part by cross forging method is approximately 70% less than other methods.

Now, accordingtostandardDIN 7523, R related to edges and corners and values of slopes are calculated for the raw preform (Fig6.-B) to produce the part as shown in Fig. 6-C.

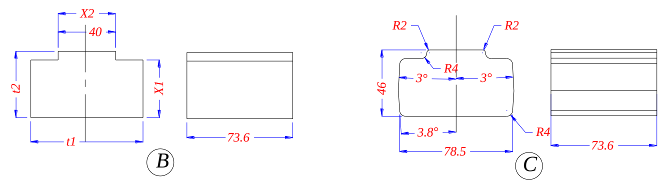


Fig. 6 Dimensions of raw preform (Fig. B) and final preform, considering slopes and R values for corners and edges (Fig. C)

Now, since the preform must be manufactured from a section with a shaped open mold by a hammer or a pressing device, dimensions of the required quadrilateral can be calculated with respect to the cross section shown in Fig. 6-C and anvil's width, according to table 3:

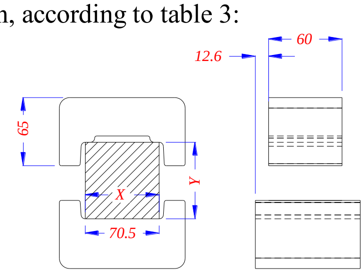


Fig. 7 MethodFor Producing The Desired Profile Using Shaped Open Die By A Hydraulic Pressing Device With Loading Range Of 20-30 Mm.

$A=A_0\times1.5 \rightarrow A_0=3475.96$ square millimeters $\rightarrow A=5213.94$ square millimeters
$X=70.5$, $Y=73$ (25)

It must be noted that magnitude of the allowable loading at each pulse is set within 20-30 mm. Otherwise, problem of "overlapping" would occur on the produced profile which would appear as cracks or cavities on surface of the part after being cooled.

Now, the resulting preform is tested once on the cross die and once on the closed die as shown in the following Fig. 10.

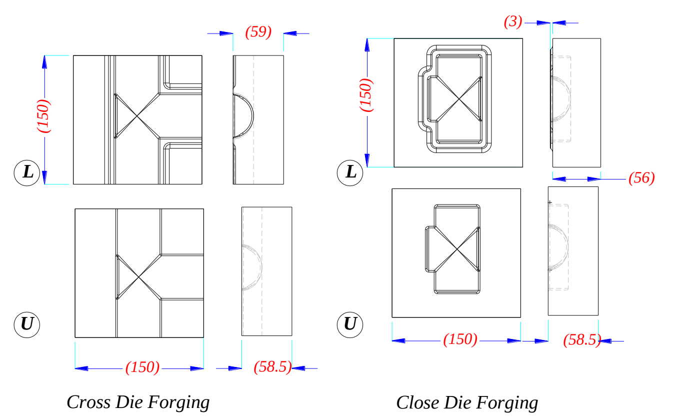
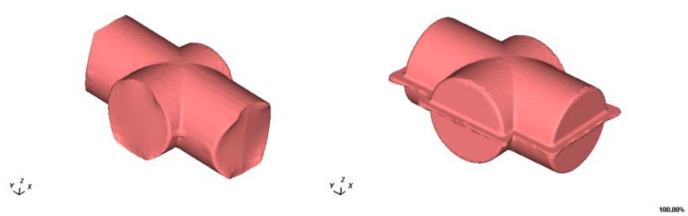


Fig.8 Left Diagram: Schematics Of The Cross Die, Right Diagram: Schematics Of The Closed Die. As Shown In The Fig.8 , The Die Is Assumed To Be Open Ended In This Case. (L=Lower Die, U: Upper Die)

Following Fig. 9 shows the parts manufactured by the close die and cross die. As expected, due to the decreased pressure inside the mold in the cross die method, material flows towards the open ends of the mold rather than flowing through the flash channel, thus material completely fills the poresand cavities in the mold and no flash is formed.



Cross Die Forging ***Close Die Forging***

Fig. 9 The Part Manufactured By Cross Die Method(Smulatied With MSC.Superforge Software)

If we compare the force-time curves obtained for the two methods (Fig.9.(a)), we observe that the force required for manufacturing the part by cross die method is one tenth (1/10) of that required by the closed die method. The approximate force calculated by table 4 (Equitation1) is almost equal to the force provided by the software.

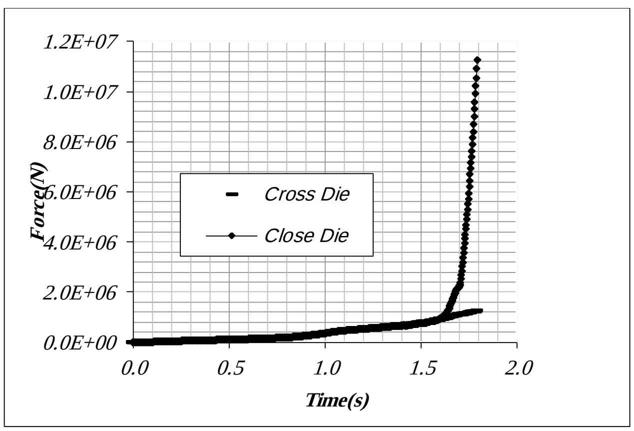


Fig.9.(a) Comparison Of The Force Required For Manufacturing The Part (Fig. 3-A) Using Closed Die And Cross Die Methods(Simulated With MSC.Superforge Software)

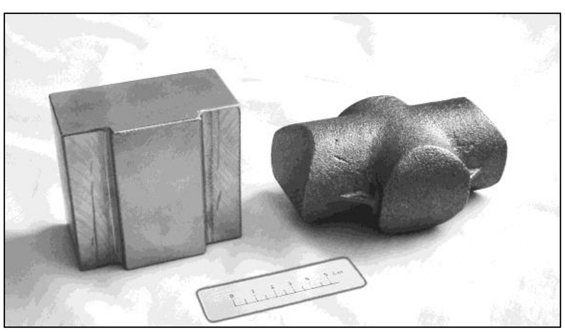


Fig. 10: The Produced Part (Valve Sample) By Mechanical Press, 315 Tons

$$r = \frac{w}{t} = 3 + 1.2 \times e^{-1.09W} \quad t = 0.89 \times \sqrt{W} - 0.017 \times W + 1.13$$ Neuberger& Mockel

$$F_{f_l} = 6.3 \times A^2 f_l \times \sqrt{\frac{1}{L_{f_l} \times V_{f_l}}} \quad , (26)$$

$$F_{f_o} = 6.3 \times A^2 f_o \times (1+r) \times \sqrt{\frac{1}{L_{f_o} \times V_{f_o}}} \quad (27)$$

$$F_T = F_{f_l} + F_{f_o} \quad (28)$$

Table 4,. Data For (Valve Sample)

W	***t***	***w***	***V_{fo}***	***L_{fo}***	***V_{fl}***	***L_{fl}***	***A_{fo}***	***A_{fl}***	***k***	***%S***	***F_T(kg)***	***F_o(kg)***	***F_l(kg)***
1.8	2.3	7.3	230416.8	100	752	115	5496.5	2711	0.302	44.8	373253.4	165297.7	207955.7

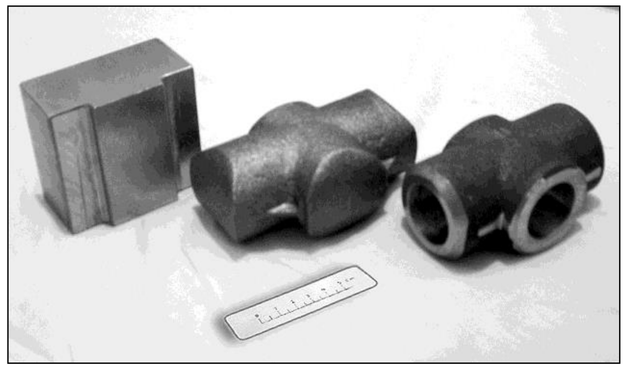


Fig. 11 Overall View Of Preform And Final Shape (Cross Die Forging)

V. Practical examples for the implementation of this method in the production wellhead valves

Usually in the forging industry segments are designed to build them is not possible with existing presses. This repetition can be seen especially in the military industry, but here we are comparing two ways to produce Gate Valve 7 1/6 "3000 PSI economically:

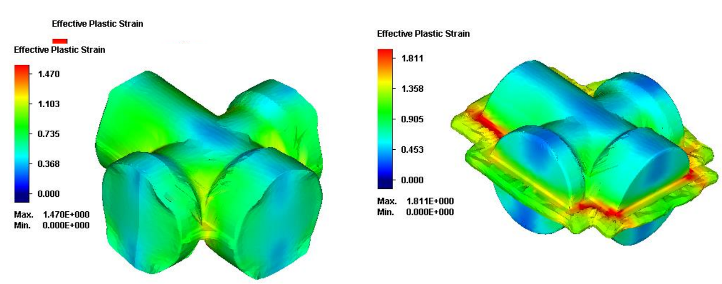


Fig. 12A Cross Die Forging Fig. 12B Closed Die Forging (SmulatiedWithMSC.Superforge Software)

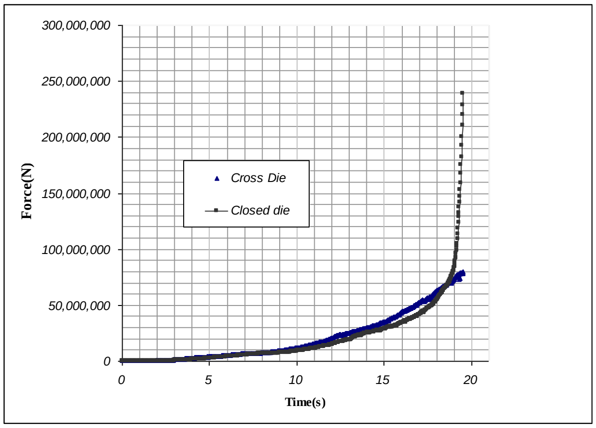


Fig. 13 Comparison Of The Force Required For Manufacturing The Part (Fig. 10a/B) Using Closed Die And Cross Die Methods(Smulatied With Msc.Superforge Software)

In order to compare costs associated with cross die method, with that of other conventional methods, a comparison was made on a profile related to a valve's body (7 1/6" 3000 Psi) between traditional and cross die methods.

A)Open dies forging method

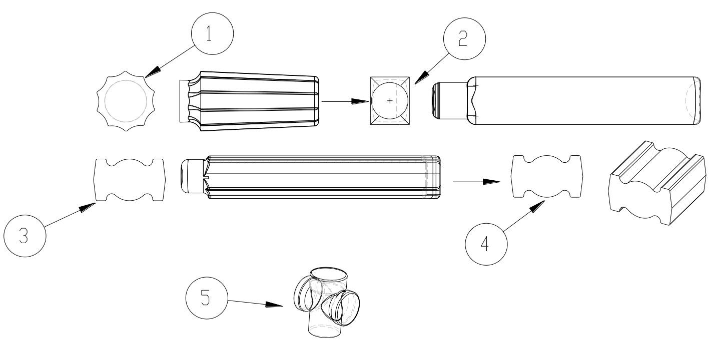


Fig. 14.(a) Overview Of Manufacturing Process For Valve's Body (7 1/16" 3000 Psi) By Profile Method

First, a 6.5 tons ingot was preheated and converted into a quadrilateral using open die forging. Then, the part was shaped into the desired profile using a shaped open mold and a hydraulic pressing device during several pulses. After being cooled down, the ingot was cut and the resulting profile was machined.

Total cost related to manufacturing the valve by conventional method (A)

Preparing the casted ingot; squeezing and converting the ingot into a quadrilateral; subjecting the ingot to tension to produce the profile; machining (rough-end mill); final machining.

1- The average original cost for producing one 4130L dodecahedral ingot with net weight of 5320: 268925200 Rials

2- The cost of transforming a dodecahedral ingot to a quadrilateral ingot after cutting process: (actual price of the work 450,900+production overhead costs 12,786,000+service overhead costs 2,695,810)* effective hours of working with pressing device at each shift 5.5= 109,949,450 Rials

3- Four ingots can be pressed at each working shift: 109,949,450/4= 27,487,360 Rials

Three valves can be produced from each ingot: Rials 296,412,560=27,487,360+268,925,200 296,412,560/3=98,804,190 Rials

4, 5 and 6- Machining and rough-end milling outside the machine manufacturing company (50000000)+CNC machining outside the machine manufacturing company (85 hours*1,200,000)=152,000,000 Rials

7- Original cost of producing a valve: 250,804,190=98,804,190+152,000,000 Rials~ **8360$**

B) Cross dies forging method

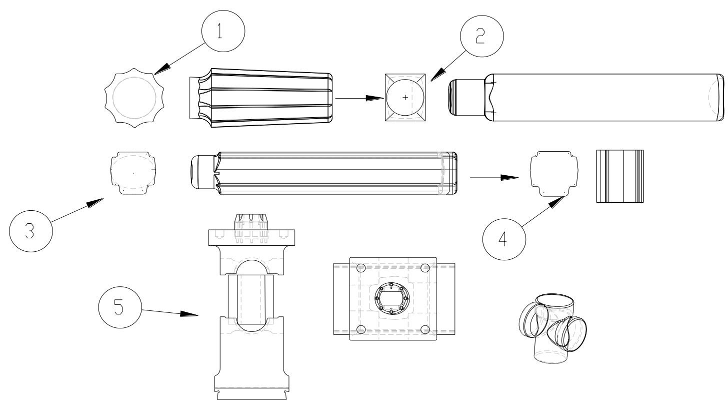


Fig. 14.(b) Overview Of Process Of Producing A Valve's Body (7 1/16" 3000 Psi) Using Cross Die Method

Similar to previous method, in this method, the resulting profile, whose dimensions were calculated according to table (3), cools down; then, it is cut to a particular length to be used as a preform for cross dies.

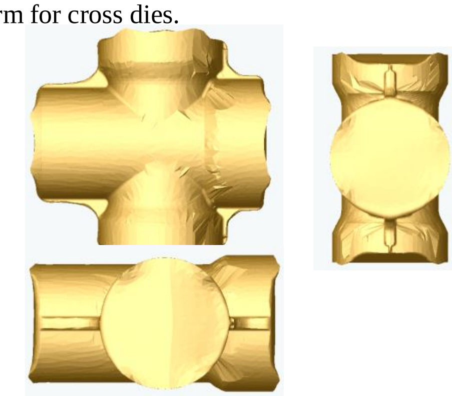


Fig. 15The Part Forged With Cross Die Method- 7 1/16" 3000 Psi Valve's Body(Smulatied With MSC.Superforge Software)

Total cost of producing a valve by cross die method (B)

Preparing the casted ingot; squeezing and converting the ingot into a quadrilateral; subjecting the ingot to tension to produce the profile; cutting and cross die forging; machining (rough-end mill); final machining.

1- The average original cost for producing one 4130L dodecahedral ingot with net weight of 5320: 268,925,200 Rials

2, 3 and 4- The cost of transforming a dodecahedral ingot to a quadrilateral ingot= 27,487,360Rials

In this method, 5 valves can be produced from one ingot: 296,412,560/5=59,282,510 Rials

5- There is 20 minutes overtime in this stage: 1/3(2,695,810+12,786,000+4,509,000)=6,663,600 Rials

Rials 65,946,110=59,282,510+6,663,600

6- Cost of machining for each valve: 50 hours*1,200,000=60,000,000

7- Original cost of producing a valve: 60,000,000+65,946,110=125,946,110Rials~ **4200 $**

Benefits of using cross die methods for production of valve's body (7 1/16" 3000Psi valve) in comparison to traditional method:

1- By using current conventional methods, three 7 1/16" 3K valve's bodies are manufactured from a dodecahedral ingot of 6.5 tons; while using the same ingot, 5 valves can be produced by cross die method.

2- Weight of the part to be forged decreases from 1247 kg to 900 kg, when using cross die method.

3- Time of machining the part decreases from 130 hours to 50 hours, in case of employing cross die method.

4- Better mechanical properties can be achieved by cross method due to higher squeezing ratio in this case. Also, it is possible to manufacture the product under PSL4 condition.

5- With regard to the oil & drilling industry's annual need to 1000 Qty. Gate Valves 7-1/16" 3000 & 5000 Psi, that much of it is imported. In case of using available presses in Iran, the amount will be about 124,858,080,000Rials (4,161,936 $) can be saved by cross die method.

VI. Results:

1- In this method, forging force can be reduce up to 80 percentage

2- This method can be used for some have forging parts which are not possible to produce theoretically

3- Cross die method is applicable only for parts that have at least one plane of symmetry.

4- Using cross die method is economical for forging parts with heavy weights and intermediate production volume.

5- In cross die method, the material flow through the flash channel is prevented by decreasing the pressure inside the mold and providing an appropriate preform design; thus, the required forging force in cross die method is 1/10 (one tenth of) closed dies.

6- In cross die method, the forged part must be in its semi-raw state and also requires machining after the final production.

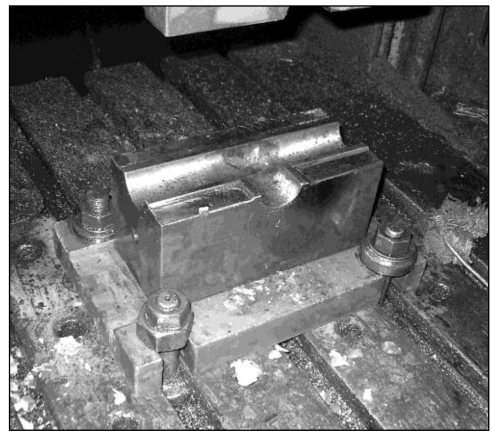


Fig. 16Image Of A Cross Die And The Mechanism By Which It Is Fixed On The Work Table Of 315 Tons Mechanical Press

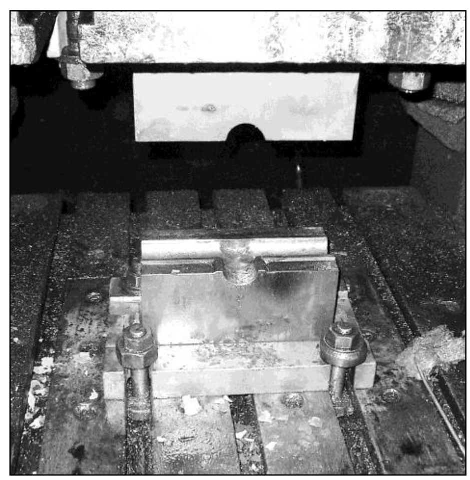


Fig. 17Cross Dies; As It Is Evident, The Entire Flash Channel Is Considered To Be On The Lower Die And Other Three Ends Of The Upper And Lower Dies Are Assumed To Be Open.

Fig. 18 315 Tons Mechanical Press Used To Test The Part

VII. NOMENCLATURE

Table 5,.Abbreviations In All Over This Article Is Unit For All Parameters

Symbol	Description and Units
W	is the weight of the forging in Kg
W_f	is the width of the flash in mm
T_f	is the thickness of the flash in mm
T_g,T_f	are the thicknesses of the gutter and the flash, respectively in mm
W_g,W_f	are the widths of the gutter and flash,in mm
F_{f_l}	Forging force in N on forging part
F_{f_o}	Forging force in N on flash channel
F_T	Total Forging force in N on flash channel + Part
A_{f_o}	Cross section of forging part in mm^2
A_{f_l}	Cross section of flash channel in mm^2

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