GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

FEM ANALYSIS OF CLOSED FORGING DIE USING ANSYS™10 AND SOLIDWORK™2007 COSMOS WORK

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ABSTRACT

In this Paper, it dealt with the influence of die geometry and temperature on closed forging die. Deformation, Von Mises strain and Von Mises stress of the die were analyzed using FEM software's Ansys™10 and Solidwork™2007/Cosmos work. The theoretical background of closed die forging and its analysis types were presented. The product and its closed forging die design have been done and the appropriate die materials were selected based on the design result. The die and the product model development have been done using CAD modeling software's. Theoretically FEM analysis and its formulation have been discussed. The analysis is done on ANSYS™10 and Solid works™ 2007 Cosmos works by varying the die fillet radius and pre heat temperature of the die. The result obtained, i.e., dies deformation, Von Mises strain and Von Mises stresses were the result obtained, discussed and presented.

The FEM analysis also provides a designer with varies forming knowledge such as material behavior, distribution of stress and strain, and elastic deformation of dies without producing the product which could be costly otherwise. The recent advancement in finite element analysis is also helps to simulate the forging process in order to predict the final forging configuration of the product. In this work, the effect of temperature and the die geometry of closed die forging is analyzed using FEM software. The analysis was done on a selected forged product called open end spanner. For the analysis, blank weight, flash dimensions and the force required for plastic deformation of the product is calculated. The die material and its type have been selected based on the calculated weight and the operating conditions.

I. INTRODUCTION

Closed die forging is one types of forging preprocess in which different types metal are deformed plastically to obtain the required product geometry. During the process there are different factors that influence its analysis that are tried to address in this thesis work using FEM software.

Forging denotes a family of processes by which plastic deformation of the work piece is carried out by compressive forces. It is one of the oldest metal working operations known and is used in making parts of widely varying sizes and shapes from variety of metals. [9]

In forging, a billet of material is plastically deformed by dies into another more complex, shape in a very short time with the help of dies, which are used to determine the final geometrical configuration of the forging. Thus, simple part geometry is transformed into a complex one, whereby the tools accommodate the desired geometry and impart pressure in the deforming material through the tool/material interface.

Forging processes usually produce little or no scrap and generate the final part geometry in a very short time, usually in one or a few strokes of a press or hammer. As a result, forging offers potential savings in energy and material, especially in medium and large production quantities. In addition for a given weight, parts produced by forging exhibit better mechanical and metallurgical properties and reliability than do those manufactured by casting or machining.[13]

Forging can be carried out at room temperature (cold working), or at elevated temperature, called warm and hot forging, depending on the temperature. The two broad categories of forging processes are open-die forging and closed-die forging. Open-die forging is carried out between flat dies or dies of very simple shape. The process is used mostly for large objects or when the number of parts produced is small. Often open-die forging is used to perform the work piece for closed-die forging. In closed-die forging the work piece is deformed between two dies halves which carry the impressions of the desired final shape. The work piece is deformed under high pressure in closed cavity, and thus precision forgings with close dimensional tolerances can be produced. [14]

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The objectives of this work is to investigate the phenomena arising inside the die during forging process, to analyze the die by varying the forging variables and simulating the entire process using finite elemental method.

In this work, the effect of temperature and the die geometry of closed die forging is analyzed using FEM software. The analysis was done on a selected forged product called open end spanner. For the analysis, blank weight, flash dimensions and the force required for plastic deformation of the product is calculated. The die material and its type have been selected based on the calculated weight and the operating conditions.

The die model is developed using CAD modeling software and the analysis is done on ANSYS and Solid work Cosmo works by varying die temperature and fillet radius of the die geometry. The results obtained from the analysis were die deformation, Von Misses strain and stresses.

II. METHODS OF CLOSED DIE FORGING

Closed Die Forging Die-design

Proper design of forging dies and selection of die materials require considerable experience and knowledge of the strength and ductility of the workpiece material, its sensitivity to strain rate and temperature, and its frictional characteristics.[10] Performance of a die measured based on quality of the forged part and reliability of the forged part.[7]

In the course of the design of a part that may be produced by closed-die forging, the following steps may, in general be followed,

1. The design of the part itself, which in many cases is a finished machined part such as a connecting road for an internal combustion engine. This stage in the design process provides the required geometry and the necessary mechanical properties. The design may originally have been made with or without a forging in mind. With perhaps some, redesign, the part may finally be made from a heavy metal stamping, for example, instead of a forging.
2. Once the decision is made to make the part by the hot-forging process, the finished forging and its dies are designed by the addition of the machining allowance and the necessary taper or draft so that the part may be readily removed from the die during the forging operation. At this stage, the forging and its dies are designed so as to fill the die cavity completely (by the addition of some extra metal that overflows to form flash) and to forge the part without any defects such as folds or overlaps. The power and energy requirements for making the finished forging are also determined at this stage.
3. If the forging is complex at all, it may have to be made in stages, so that the necessary perform or blocker dies may have to be designed to distribute the metal adequately. The geometry of the forging slug (stock) or multiple is determined.

Due to the value of the surface-to-volume ratio the heat loss from the flash occurs at a much greater rate than in the die cavity. Because of the difference in volume and in the incremental energy input, the heat generated in different zones is different. [19]

The main objective of forging process design is to ensure adequate flow of the metal in the dies so that the desired finished part geometry can be obtained without defects and with prescribed properties. Metal flow is greatly influenced by part or die geometry often several operations (performing or blocking) are needed to achieve gradual flow of metal from an initially simple shape (cylinder or round-cornered square billet) into more complex shape of the final forging. [11]

Design of blocker and perform geometry is the most critical part of forging die design. The blocker operation has the purpose of distributing the metal adequately within the blocker (or perform) to achieve the following objectives.

- Filling the finisher cavity without any forging defects
- Reducing the amount of material lost as forging flash
- Reducing die wear by minimizing metal movement in the finisher die
- Producing the required amounts of deformation and grain flow so that desired forging properties are obtained.[11]

Materials of Die

Die material, generally can be categorized as hot working, cold working and shock- resistance die. Hot working die steels (AISI H series) are designed for use at elevated temperatures and have high toughness and high resistance to wear and cracking. The alloying elements are general tungsten, molybdenum chromium and vanadium. [10] The detail composition of hot working die steels are presented in the table below.

Cold working die steels (A, D, and O series) are used for cold-working operations. They generally have high resistance to wear and cracking. Shock resisting die steels (S series) are designed for impact toughness and are used in applications such as header dies, punches, and chisels.[10]

The number after the latter ‘H’ indicates the base of the die material made from. The hot working die ranging from H1 to H19 is usually called chromium based die, from H20 to H39 tungsten based and from H40 to H59 molybdenum based. [10]

Die materials for hot forging should have good hardenability as well as resistance to wear particularly abrasive wear as of the presence of scale on heated forging [10], plastic deformation, thermal fatigue and heat checking, and mechanical fatigue. Die design is also important in ensuring adequate die life; poor design can result in premature wear or breakage. [26]

Hot-work die steels are commonly used for hot-forging dies subjected to temperatures ranging from 315 °C to 650 °C (600 °F to 1200 °F). These materials contain chromium, tungsten, and in some cases, vanadium or molybdenum or both. These alloying elements induce deep hardening characteristics and resistance to abrasion and softening. These steels usually are hardened by quenching in air or molten salt baths. The chromium-base steels contain about 5% Cr. High molybdenum content gives these materials resistance to softening; vanadium increases resistance to abrasion and softening. Tungsten improves toughness and hot hardness; tungsten-containing steels, however, are not resistant to thermal shock and cannot be cooled intermittently with water. The tungsten-base hot-work die steels contain 9 to 18% W, 2 to 12% Cr, and sometimes small amounts of vanadium. The high tungsten content provides resistance to softening at high temperatures while maintaining adequate toughness, but it also makes water cooling of these steels impossible. [26]

Low-alloy proprietary steels are also used frequently as die materials for hot forging. Steels with ASM designations 6G, 6F2, and 6F3 have good toughness and shock resistance, with good resistance to abrasion and heat checking. These steels are tempered at lower temperatures (usually 450 °C to 500 °C, or 840 °F to 930 °F); therefore, they are more suited for applications that do not result in high die surface temperatures, for example, die holders for hot forging or hammer die blocks. [26]

Selection of die materials mainly depends on die size, composition and properties of the workpiece, complexity of its shape, forging temperature, type of operation, cost of die material, number of forgings required, and the heat transfer and distortion characteristics of the die material.[10]

Die materials in shops in which die practice is the same for stainless steel as for carbon and alloy steels, die materials are also the same. In shops in which special consideration is given to dies for stainless steel, small dies (for forgings weighing less than 9 kg,) are made solid from hot-work tool steel, such as H11, H12, or H13.[10] For our case, since weight of the spanner is less than 9kg, then it is possible to use the either of H11, H12 or H13 die.

Factors in the Selection of Die Materials

Properties of materials that determine their selection as die materials for hot forging are

- Ability to harden uniformly,
- Wear resistance (ability to resist the abrasive action of hot metal during forging)
- Resistance to plastic deformation (ability to withstand pressure and resist deformation under load)
- Toughness
- Resistance to thermal fatigue and heat checking
- Resistance to mechanical fatigue

Ability to Harden Uniformly

The higher the hardenability of a material, the greater will be the depth to which it can be hardened. Hardenability depends on the composition of the tool steel. In general, the higher the alloy content of steel, the higher its hardenability, as measured by the hardenability factor *D*1 (in inches). The *D*1 of a steel is the diameter of an infinitely long cylinder which would just transform to a specific microstructure (50% martensite) at the center if heat transfer during cooling were ideal, that is, if the surface attained the temperature of the quenching medium instantly. A larger hardenability factor *D*1 means that the steel will harden to a greater depth on quenching, not that it will have a higher hardness. For example, the approximate nominal hardenability factors *D*1 (inches) for a few die steels are as follows: ASM 6G, 0.6; ASM 6F2, 0.6; ASM 6F3, 1.4; AISI H10, 5; AISI H12, 3.5.

Table 1. Compositions of tool and die materials for hot forging

Designation	Nominal Composition %								
	C	Mn	Si	Co	Cr	Mo	Ni	V	W
Chromium-base AISI hot-work tool steels									
H10	0.4	0.4	1.0	-	3.3	2.5	-	0.5	-
H11	0.35	0.3	1.0	-	5.0	1.5	-	0.4	-
H12	0.35	0.4	1.0	-	5.0	1.5	-	0.5	1.5
H13	0.38	0.3	1.0	-	5.25	1.5	-	1.0	-
H14	0.40	0.35	1.0	-	5.0	-	-	-	5.0
H19	0.40	0.3	0.3	4.25	4.25	0.4	-	2.1	4.1
Tungsten AISI hot-work tool steels									
H21	0.30	0.3	0.3	-	3.5	-	-	0.45	9.25
H22	0.35	0.3	0.3	-	2.0	-	-	0.4	11.0
H23	**0.3**	0.3	0.3	-	12.0	-	-	1.0	12.0
H24	0.45	0.3	0.3	-	3.0	-	-	0.5	15.0
H25	0.25	0.3	0.3	-	4.0	-	-	0.5	15.0
H26	0.5	0.3	0.3	-	4.0	-	-	1.0	18.0
Low-alloy proprietary steels									
ASM 6G	0.55	0.8	0.25	-	1.0	0.35	-	0.1	-
ASM 6F2	0.55	0.75	0.25	-	1.0	0.3	1.0	0.1	-

Wear Resistance

Wear is a gradual change in the dimensions or shape of a component caused by corrosion, dissolution, or abrasion and removal or transportation of the wear products. Abrasion resulting from friction is the most important of these mechanisms in terms of die wear. The higher the strength and hardness of the steel near the surface of the die, the greater its resistance to abrasion. Thus, in hot forming, the die steel should have a high hot hardness and should retain this hardness over extended periods of exposure to elevated temperatures.

Resistance to Plastic Deformation

The yield strengths of steels decrease at higher temperatures. However, yield strength also depends on prior heat treatment, composition, and hardness. The higher the initial hardness, the greater will be the yield strength at various temperatures. In normal practice, the level to which die steel is hardened is determined by toughness requirements: the higher the hardness, the lower the toughness of steel. Thus, in metal-forming applications, the die block is hardened to a level at which it should have enough toughness to avoid cracking.

Resistance to Heat Checking.

Non-uniform expansion, caused by thermal gradients from the surface to the center of a die, is the chief factor contributing to heat checking. Therefore, a material with high thermal conductivity will make dies less prone to heat checking by conducting heat rapidly away from the die surface, reducing surface-to-center temperature gradients, and lessening expansion/contraction stresses. The magnitudes of thermal stresses caused by non-uniform expansion or temperature gradients also depend on the coefficient of thermal expansion of the steel; the higher the coefficient of thermal expansion, the greater the stresses. From tests in which the temperature of the specimen fluctuated between 650 °C (1200 °F) and the water-quench bath temperature, it was determined that H10 was slightly more resistant to heat checking or cracking after 1740 cycles than were H11, H12, and H13. After 3488 cycles, H10 exhibited significantly more resistance to cracking than did H11, H12, and H13.

Fatigue Resistance

Mechanical fatigue of forging dies is affected by the magnitude of the applied loads, the average die temperature, and the condition of the die surface. Fatigue cracks usually initiate at points at which the stresses are highest, such as at cavities with sharp radii of curvature whose effects on the fatigue process are similar to notches. Other regions where cracks may initiate include holes, keyways, and deep stamp markings used to identify die sets.

Redesigning to lower the stresses is probably the best way to minimize fatigue crack initiation and growth. Redesigning may include changes in the die impression itself or modification of the flash configuration to lower the overall stresses. Surface treatments may also be beneficial in reducing fatigue-related problems. Nitriding, mechanical polishing, and shot penning are effective because they induce surface residual (compressive) stresses or eliminate notch effects, both of which delay fatigue crack initiation. On the other hand, surface treatments such as nickel, chromium, and zinc plating, which May be beneficial with respect to abrasive wear, have been found to be deleterious to fatigue properties.

Metal Flow in Closed Die Forging

Closed-die forging is a very complex forming process from the point of view of the mechanics of deformation or metal flow. It is difficult to analyze, because of such factors non-steady state and non-uniform metal flow, the variable interface friction, and the unsteady state of heat flow between the material being deformed and the dies, all of which present a real challenge to evaluation. Also the mean strain rate and temperature are not constant during forging and vary from one zone of deformation to another, and in addition they change continuously as the deformation proceeds. [19]

Three main stage of deformation or metal flow occur in closed die forging. They are upsetting, die filling and end of forging.

1. Upsetting- in which the forging slug is initially compressed resulting in outward flow of metal to form the flange and inward and upward flow to extrude the boss or shaft.
2. Die filling-in which the lower cavity is essentially filled, except perhaps for the upper portion of the shaft, and the flash begins to form.
3. End of forging-in which the dies are completely filled as the load and the pressure within the die cavity rapidly rises due to the restriction of the metal flow to form the colder, thinner flash with and excess metal flowing into the flash gap and gutter.

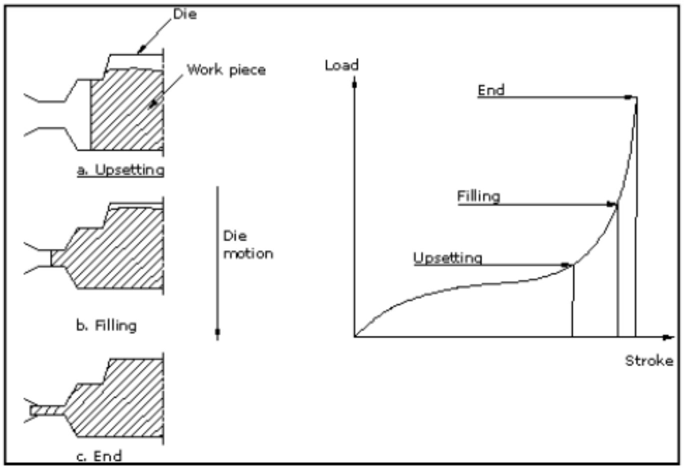

Figure 1 Illustration of metal flow and load stroke curve

Die Failures

Failure of dies in manufacturing operations generally result from one or more of the following causes: improper design, defective material, improper heat treatment and finishing operations, overheating and heat checking (cracking caused by temperature cycling), excessive wear, overloading, misuse, and improper handling. [10]

We describe in the following paragraphs some of the important factors leading to die failure. These factors apply to dies made of die steels, but many are also applicable to other die materials. In order to withstand the forces in manufacturing processes, a die must have proper cross sections and clearances. Sharp corners, radii, and fillets, as well as sudden changes in cross-sections, act as stress raisers and have detrimental effect on die life. Dies may be made in segments and pre-stressed during assembly for improved strength.

The proper handling, installation, assembly, and aligning of dies are important. Overloading of tools and dies can cause premature failure. In ASM hand book mentions the most critical factor for premature die filers re are overloading of the die, abrasive action, and overheating.[26] As it is known die may be failed mechanically, thermally and permanently deformed. As was mentioned in ASM hand book, abrasive wears are responsible for mechanical wear, overheating for thermal wear and overloading for permanent deformation of dies.

Overloading

Although fewer die failures can be ascribed to overloading than to abrasion or overheating, an overloaded die wears rapidly and may break. Overloading can be avoided by careful selection of die steel and hardness, use of blocks and inserts of adequate size, proper application of working pressures, proper die design to ensure correct metal flow, and proper seating of the dies in the hammer or press. Overloading from inadequate hammer or press capacity should not be compensated by overheating the work metal. [26]

Overheating

As a die becomes hotter, it’s resistance to wear will decreases. Overheating causes most of the premature die wear that occurs in forging. Overheating is likely to occur in areas of the die impression that project into the cavity. In addition, overheating may result from continuous production. If an internal die-cooling system that is adequate to prevent overheating cannot be provided economically, dies, or portions of dies that are susceptible to overheating should be constructed of steels with high heat resistance. [26]

Forging defects

In closed die forging defects occur during the forging process. Incomplete die filing, die misalignment, cracking and cold shuts are some of the defects usually occur in closed die forging.

Cracking can occur as a result of excessive working of the surface at too low a temperature or as a result of hot shortness. A high sulfur concentration in the furnace atmosphere can produce hot shortness in steel and nickel. Cracking at the flash of closed-die forgings is another defect, since the crack generally penetrates into the body of the forging when the flash is trimmed off. This type of cracking is more prevalent the thinner the flash in relation to the original thickness of the metal. Flash cracking can be avoided by increasing the flash thickness or by relocating the flash to a less critical region of the forging. It also may be avoided by hot trimming or stress relieving the forging prior to cold trimming of the flash. [27]

Another common surface defect in closed-die forgings is the cold shut, or fold. A cold shut is a discontinuity produced when two surface of metal fold against each other without welding completely. This can happen when metal flows past part of the die cavity that has already been filled or that is only partly filled because the metal failed to fill in due to sharp corner, excessive chilling, or high friction. A common cause of cold shuts is too small a die radius. [27]

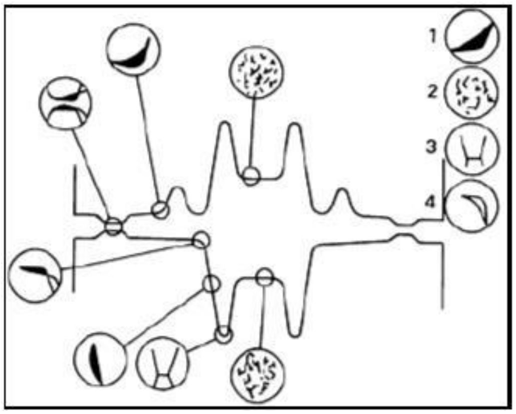

Figure 2 Common failure mechanisms for forging dies, 1. Abrasive wear,2. Thermal fatigue, 3. Mechanical fatigue, 4. Plastic deformation [26]

For example, nonsymmetrical parts like connecting rods can often be forged in pairs minimizing off-center force. Furthermore, ram deflection is minimized by locating the blocker and finisher impressions as close to the center of the die as possible. Some deflection still occurs, but it can be corrected by building a compensating mismatch into the die impressions. Because the blocker impression does most of the work in the forging of connecting rods, the mismatch is built into this impression, in a direction opposite that of ram deflection. The amount of built-in misalignment varies with the offset from center, the size and shape of the forging stock, and the equipment used. In the forging of automotive connecting rods from 35 mm diameter stock in a 13.3 kN hammer, a 0.76 mm misalignment in the dies was optimum. [10]

Die locks and counter locks are sometimes used to ensure proper alignment of the upper and lower dies. These locks consist of male and female components (projections and recesses) that are located on the parting surfaces of the dies to provide close-fitting junctions when the dies are closed. Because they are expensive to produce and require frequent maintenance or replacement, die locks are generally used only when the contours of the forging prevent the use of alternative methods for limiting or eliminating die misalignment. [26]

Design of Forging Die and product for Open End Spanner

Calculation of Blank size

Work piece type to be forged-open end spanner 13-14
Raw material –Chromium-vanadium Steel
Designation- AISI 6150

Mechanical Properties

Table 2. Mechanical Properties of AISI 6150 chromium vanadium steel

Density (×1000 kg/m^3)	7.7-8.03
Poisson's Ratio	0.27-0.30
Elastic Modulus (GPa)	190-210
Tensile Strength (Mpa)	667.4
Yield Strength (Mpa)	412.3
Elongation (%)	23.0
Reduction in Area (%)	48.4
Hardness (HB)	197
Impact Strength (J)	27.4
(*Izod*)	

Bar Diameter- 17mm
Weight of finished forged spanner,

$$m_f = 0.16kkg$$

To calculate weight of blank or mass required, m_{req},
It is known that,

$$m_{req} = Wm_f$$

Where,

W is weight factor is equals to be 1.1 taken from table (4.5) categorizing the spanner as shape group 1
Therefore, the mass required,

$$m_{req} = 1.1X0.16$$
$$= 0.176Kg$$

Die Block Dimension

Maximum thickness of the spanner is about 6mm. half of the thickness, 3mm, of the spanner impressed in the upper half of the die and the remaining half in the lower die block. There is a correlation between fillet/corner radii with height of the part given [20] in table (3)

Table 3. Minimum block dimension

Depth of Cavity h, mm	Minimum thickness in mm	Minimum die block height H in mm
10	20	100
25	40	160
40	56	200
63	80	250
100	110	315

For this case, since the minimum height of cavity given in the table (4.3) is 10 and taking the corresponding minimum dimensions of the die block, i.e., minimum thickness 20mm and minimum die block height 100mm. Since the value given in the table is the minimum, it would not be safe to take this value for the actual dimensions of die block. Though it would be checked to the optimum value during the analysis, for convenience let us increase the two dimensions by 15% and calculate the overall dimensions of the die block including spanner width, 14mm is the maximum.

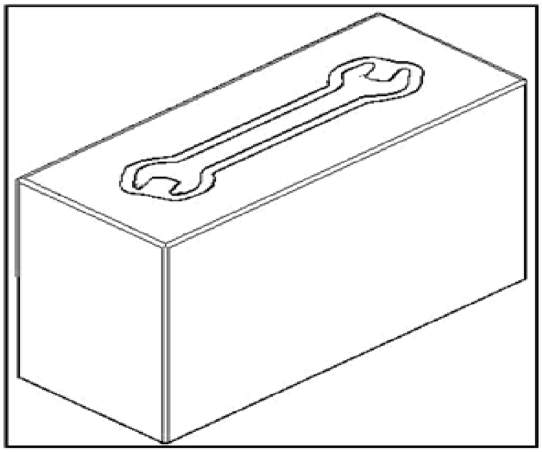

Figure 3 Die Block with Spanner impression

First, the area of each cross section along the length of the pre-form must be equal to the area of the finished cross section augmented by the area necessary for flash. Thus, the initial stock distribution is obtained by determining the areas of cross sections along the main axis of the forging. Second, all the concave radii (including fillet radii) of the pre-form should be larger than the radii of the forged part. Finally, whenever practical, the dimensions of the pre-form should be larger than those of the finished part in the forging direction so that metal flow is mostly of the upsetting type rather than of the extrusion type. During the finishing operation the material then will be squeezed laterally toward the die cavity without additional shear at the die/material interface. Such conditions minimize friction and forging load and reduce wear along the die surfaces. [26]

AS the geometry of becomes more complex, more than one performing or pre-blocking operation become necessary to forge defect free parts starting from stock having a relatively simple shape. The die design sequence is the reverse of the forging sequence. In the design sequence the dimensions and geometry of the finished part are modified to yield the shape of the finish forging and its die cavity. The geometry of the blocker is then used to design the per-form or pre-blocker and its cavity.

. In the case of the drop hammer forging of an open-end spanner, a product selected for this thesis work, the forging blank is first pre-formed by fullering by open die forging on the face of the die block to proportion the metal correctly for the filling of the shaping or blocker die cavity. The die is designed in such manner that most of the flow and consequent wear occurs in the blocker cavity. The finisher cavity is used to impart accurate dimensions to the forging and the fine detail. Generally a minimum amount of flow occurs in the finisher cavity, so as to reduce the load wear, in order to preserve its accuracy and fine detail. In this case, for spanner, four different forging blanks or workpieces are involved.

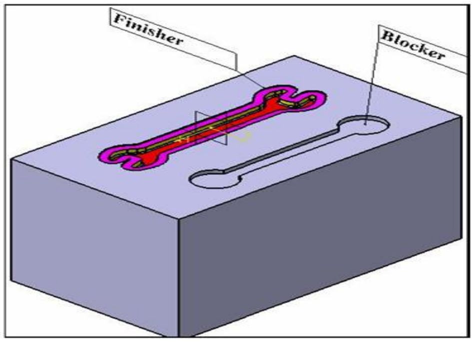

Figure 4 Multiple closed-die forging die

The initial forging blank cut from the bar or billet,

1. The blocker perform and
2. The finisher forging, this is normally machined to produce the required part.

However, for small size product, fullering, edging, pre-forming and finishing can be accommodated in one piece die block and all the operations are then performed turn by turn. For the spanner case the complexity of the spanner geometry is simple, then only blocking and finishing are required to get accurate product.

Table 4. AISI Type H11 Hot Work Tool Steel Properties [33]

Physical Properties	Metric
Density	7.80 g/cc
Mechanical Properties	metric
Hardness, Knoop	642
Hardness, Rockwell C	56
Hardness, Vickers	621
Tensile Strength, Ultimate	1990 MPa
Tensile Strength, Yield	1650 MPa
Elongation at Break	9.00 %
Modulus of Elasticity	210 GPa
Bulk Modulus	140 GPa
Poisson Ratio	0.30
Charpy Impact	18.0 J
Machinability	45.0-55.0 %
Shear Modulus	81.0 GPa
Thermal Properties	Metric
CTE, Linear	11.0µm/m-°C @Temperature 25.0 - 95.0 °C
	12.4µm/m-°C Temperature 25.0 - 540 °C
Specific Heat Capacity	0.460J/g-°C@ Temperature 0.000 - 100 °C
Thermal Conductivity	24.6W/m-K@ Temperature 215 °C
	42.0W/m-K@ Temperature 23.0 °C

Table 5 Mass ratio factor W as f(m_f and shape group)

M_f in kg		1.0	2.5	4.0	6.3	20	100
W with shape group	1	1.1	1.08	1.07	1.06	1.05	1.03
	2	1.25	1.19	1.17	1.15	1.08	1.06
	3	1.5	1.46	1.41	1.35	1.20	-

Table 6. Flash land ratio w/s=f(A_s and the type of deformation)

A_s in mm^2	**w/s mainly for**		
	upsetting	**Lateral flow**	**Vertical flow**
Up to 2000	8	10	13
2001-5000	7	8	10
5001-10000	5.5	6	7
10001-25000	4	4.5	5.5
26000-70000	3	3.5	4.5
71000-150000	2	2.5	3.5

FEM analysis of Closed Forging Die Using Ansys™10 and Solidwork™2007 Cosmoswork

Solidwork™ 2007 Cosmoswork Structural Analysis of Closed Forging Die

COSMOS Works is a design analysis automation application fully integrated with Solid Works. This software uses the Finite Element Method (FEM) to simulate the working conditions of and predict their behavior. FEM requires the solution of large systems of equations. Powered by fast solvers, COSMOS Works makes it possible for designers to quickly check the integrity of their designs and search for the optimum solution.

In Solid work cosmos structural analysis Von Misses stress and strain, deformation and displacement are obtained.

In this thesis work, the analysis is done by varying fillet radius of the die at its inner side (outer periphery of the spanner) and the analysis was done on Linear Static analysis type of cosmos work.

The maximum pressure load applied was 2e9N/m^2 Die material used-Hot work tool steel H11

Table 7. Properties of H11 Die Tool Steel [33]

No	***Description***	***H11***
1	Density , (Kg/m^3)	7800
2	Tensile Strength, Ultimate, (MPa)	1990
3	Tensile Strength, Yield , (MPa)	1650
4	Poisson Ratio	0.3
5	Modulus of Elasticity , (GPa)	210
6	CTE, linear at 250-540 ^{0}c (µm/m^{0}c)	12.4
7	Specific Heat Capacity @0-100^{0}C, (J/Kg^{0}C)	460
8	Thermal Conductivity,@Temp23^{0}C, (W/m-k)	42
	@temp215^{0}C, (W/m-k)	24.6
9	Shear Modulus , (GPa)	81

Ansys™10 structural Analysis of Closed Forging Die

There are seven types of structural analyses available in the ANSYS family of products, namely static, modal, harmonic, transient dynamics, spectrum and buckling analysis. The primary unknowns (nodal degrees of freedom) calculated in a structural analysis are displacements. Other quantities, such as strains, stresses, and reaction forces, are then derived from the nodal displacements.

Structural analyses are available in the ANSYS Multi physics, ANSYS Mechanical, ANSYS Structural, and ANSYS Professional programs only. Ansys Multi physics is used in this case.

The type of Structural analysis appropriate for closed die forging analysis is the static analysis.
The static analysis is used to determine displacements, stresses, etc. under static loading conditions, both linear and nonlinear static analyses. Nonlinearities can include plasticity, stress stiffening, large deflection, large strain, hyper elasticity, contact surfaces, and creep.

For the closed die forging analysis a pre-heated die at 200 ^{0}C and a 2000N/mm^2 pressure load was applied on the recesses of the product. The analysis was done by varying the fillet radius of corner of the recesses, 0, 0.25, 0.5, 0.6, 0.75 and 1mm radius. The recommended value of fillet radius empirically related with thickness of the product, i.e 1/10th to 1/20th of the thickness. [20]

The elements used for the analysis were solid 185, solid 186and solid187due to their typical properties of plasticity, hyper elasticity, stress stiffening, creep, large deflection, and large strain capabilities. Their detail properties are described as follows.

SOLID185 Element Description
SOLID185 is used for the 3-D modeling of solid structures. It is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyper elasticity, stress stiffening, creep, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastic plastic materials, and fully incompressible hyper elastic materials.

SOLID185 Input Data
The element is defined by eight nodes and the orthotropic material properties. The default element coordinate system is along global directions. Pressures may be input as surface loads on the element faces. Temperatures may be input as element body loads at the nodes.

SOLID186 Element Description
SOLID186 is a higher order 3-D 20-node solid element that exhibits quadratic displacement behavior. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element supports plasticity, hyper elasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastic plastic materials, and fully incompressible hyper elastic materials.

SOLID186 Input Data
Pressures may be input as surface loads on the element faces and positive pressures act into the element. Temperatures may be input as element body loads at the nodes.

SOLID187 Element Description
SOLID187 element is a higher order 3-D, 10-node element. SOLID187 has a quadratic displacement behavior and is well suited to modeling irregular meshes (such as those produced from various CAD/CAM systems).

The element is defined by 10 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyper elasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elasto plastic materials, and fully incompressible hyper elastic materials.

SOLID187 Input Data

In addition to the nodes, the element input data includes the orthotropic or anisotropic material properties. Orthotropic and anisotropic material directions correspond to the element coordinate directions. Pressure and temperature may be the input

In the following analysis element type 185 is used as the model can be meshed easily while doing the analysis compare to the other element types.

III. RESULT & DISCUSSION

In this work, closed forging die used for spanner manufacturing analyzed using the analysis software i.e., Ansys™10 and Solidwork™2007 cosmos work.

Fillet radius, die material type and initial temperature (die-preheating) were the variables that varied over the analysis by keeping the applied pressure which is the maximum that the die could carry.

The effect of friction in this analysis was neglected since the thickness of the spanner was not more than 6mm and it was performed using pre-form die in such a way that only minimum deformation would be possible. Therefore, the lateral and vertically material flows would be minimum that the friction factor could not have considerable effect on the process of the spanner forging. Therefore, incorporating friction effect could not bring significant effect over the process analysis of this case.

The result obtained on the external profile of the spanner (internal corner of the die) shows different values of stress, strain and deformation for different fillet radius taken at the die corner. The sample fillet radius taken for the analysis were 0, 0.25, 0.5, 0.6, 0.75 and 1mm. 0.6 fillet radius was taken as a reference point as it was the literature recommended value.

From design point of view, fillet is required for proper handling of the spanner and good appearance. While using the spanner, the edge should not hurt the person who is using it. Therefore, it is essential removing the edge made a fillet. However this fillet has great impact on the die in which the spanner is produced from failure point of view

The analysis was done on H11 hot tool material with different fillet radius and die pre-heating condition, i.e, without pre-heating and with pre-heating of the die with a temperature magnitude of 200 ^{0}C.It was, therefore, observed from the result that at 0.5 and 0.6mm fillet radius, the stresses developed are minimum at both conditions of die, without and with pre-heating conditions, at the particular place where the fillet was made and around the place where the fillet was made. The places are indicated with different spectrum of colors in the analysis result figures of both software.

In Ansys™10 analysis, different options were available for selecting appropriate element types for the analysis, but with the difficulty of getting proper mesh during the analysis, the other element type are left out and only element types of solid185 has been taken for the analysis.

The result obtained from both types of analysis are having slight difference with each other that comes due to the error committed while giving the necessary inputs and while doing selection on element or nodes on the model, specially on ansys™10. The other cause may be the element sizes used in both software may be sometimes different with that of the other, as element size determines the accuracy of the result and computation time of the computer. In Ansys™10, compared to cosmoswork it was difficult to get meshed elements of the model and sometimes needs to try again and again by changing the element sizes till to get meshed mode, at this time, therefore, result variation could be occurred.

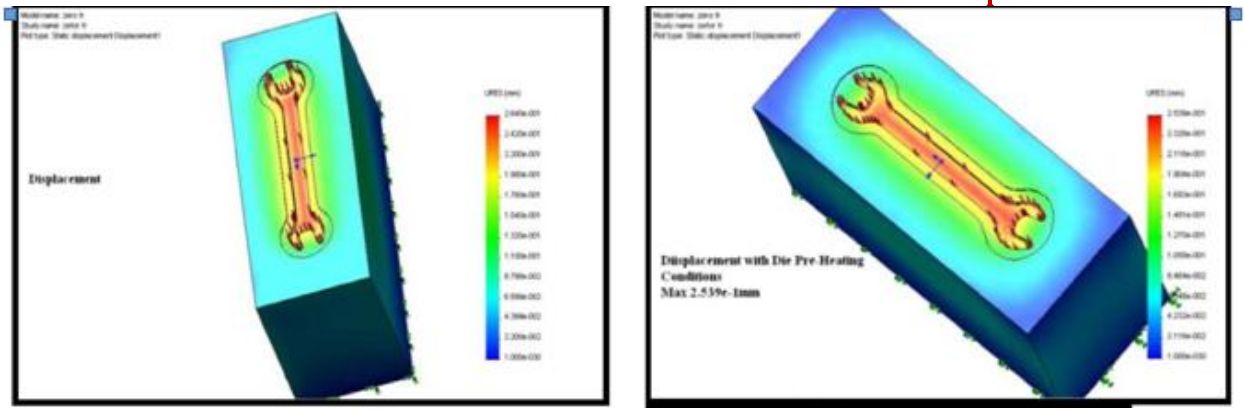

Figure 5 Analysis with zero Fillet Radius

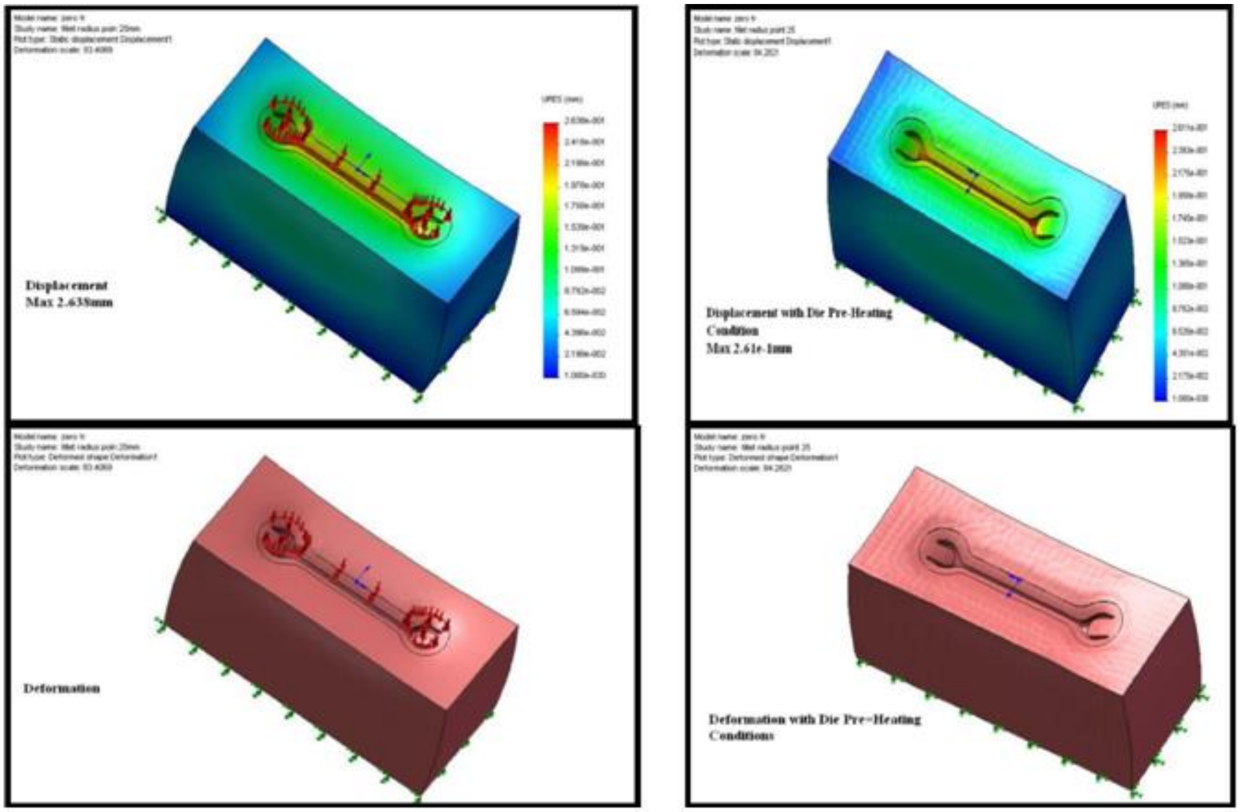

Figure 6 Analysis with 0.25mm Fillet Radius

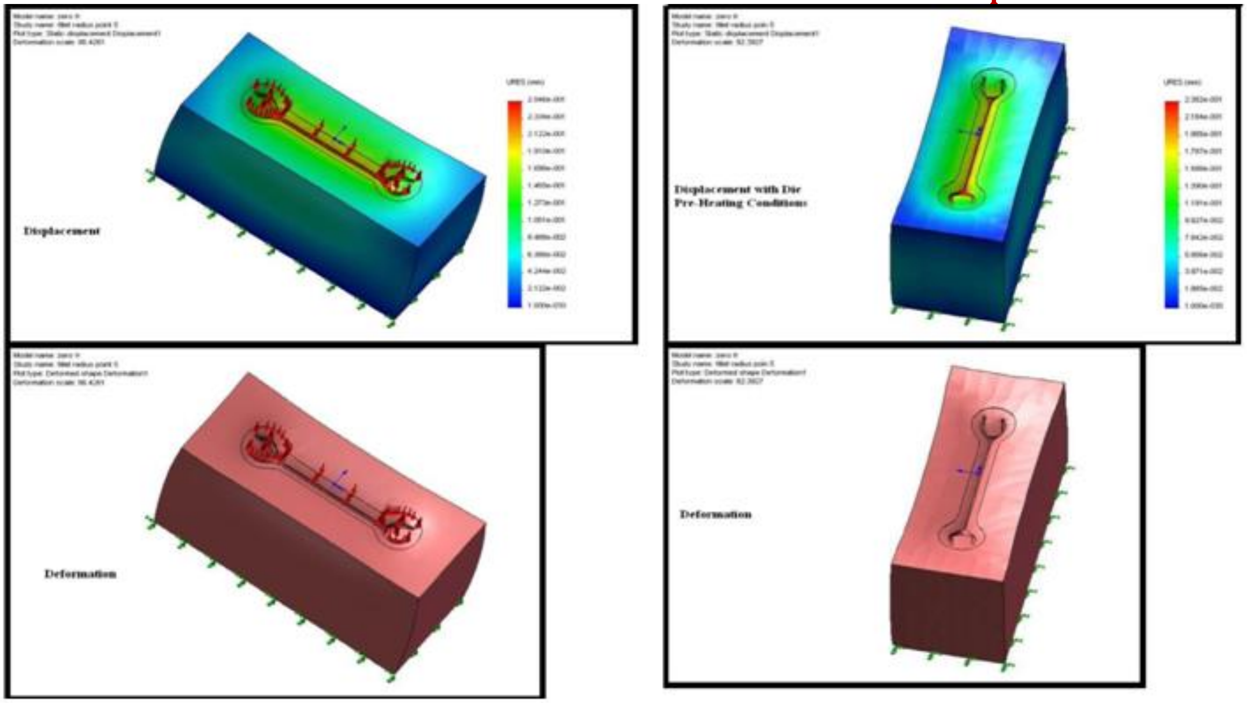

Figure 7 Analysis with0.5mm Fillet Radius

In this project work a finite element analysis of metal forming process i.e, closed die forging was investigated by considering mathematical models developed so far including: slab methods, slip-line methods, upper and lower bound analysis methods and visoplasticity method. The suitability of the mathematical models was examined in order to choose the one which is capable of modeling the complex metal forming phenomena which usually occurs in closed die forging.

Particularly the factors affecting the closed die forging i.e., friction, material properties, product geometry, forging temperature, and die material were considered while selecting the mathematical model for this analysis work. Ultimately after analyzing the pros and cons of each of these methods the slab method was selected to develop the mathematical model of closed die forging.

After developing the mathematical model the author designed a closed forging die by considering an example part i.e., an open ended spanner, selected from the former products of Akaki Spare Parts Share Company (ASPSC) and analyzed the process of closed die forging. Further in this thesis work the design of the die were optimized using FEM methods by Appling different software tools including ANSYS™10 Solidworks2007/COSMOS works ™.

The following are the main results of this analysis conducted using this work:

- The fillet radius has a significant effect on the stresses and strains generated on the die in particular on the part of the die where the product shape is complex,
- The increase of fillet radius results on the reduction of stress on the fillet, while reduction of fillet radius results increases of the stress around neighboring faces of the die which is responsible for fatigue crack development and leads to early die failures ,
- Considering the example part i.e., the open end spanner, after testing various fillet radiuses we found the value that could cause the minimum fillet radius is about 0.5-0 to 0.6 mm. This amount does not affect the overall shape of the spanner, its appearance and strength.
- Preheating the die is a very essential procedure in closed die forging in order to reduce the surface-to-center temperature gradient which could cause non-uniform expansion and impair the die life, and

- For the example part different amounts of preheat temperature were tested and for the given combination of parameters the amount of preheat should be between 150-200 ^{0}C for better tool life.

Non-uniform expansion, caused by thermal gradients from the surface to the center of a die, is the chief factor contributing to heat checking.

As discussed in the above paragraphs the author has attempted to optimize closed die forging process, by considering, different die materials, fillet radius, and amount of preheat to optimize the geometry and the life of the die by considering the above mentioned example part.

Thus this work is a good demonstration of the potential of FEM analysis for optimal design of close die forgings; which is basically done by trial and error methods. Particularly this work can be extended for complex die forging where enormous amount of time and resource is spent before developing new complex die geometry.

REFERENCES

1. *J.H. Song, Y.T. Im, Process Design for Closed-Die Forging of Bevel Gear by Finite Elemental Analyses, Journal of Material Processing Technology 192-193(2007) 1-7.*
2. *Victor Vazquez, Taylan Altan, New Concepts in Die Design-Physical and Computer Modeling Applications, Journal of Material Processing Technology 98 (2000) 212-223*
3. *M. Joglaf, S.B. Sulaiman, M.K.A. Ariffin and A.A. Faieza, Closed Die Forging Geometrical Parameters Optimization for Al-MMC, American J. of Engineering and Applied Sciences 1 (1):1-6, 2008.*
4. *A. B. Abdullah, M.J. Embi, A.M.S. Hamouda and Shuib, Effect of Design and Process Parameter to Cold Forging Die Design: A Finite Element Analysis, Journal of Applied Sciences 7 (5): 777-784, 2007.*
5. *M. Skunca, P. Skakun, Z. Keran, L. Sidjainin, M.D. Math, Relations Between Numerical Simulation and Experiment in Closed Die Fortging of a Gear, Journal of Material Processing Technology 177(2006) 256-260.*
6. *B.Tomov, Hot Closed Die Forging-State-of-Art and Future Development, Journal of Achievements in Materials and Manufacturing Engineering, Volume 24, Ussue 1, Sept 2007.*
7. *Guoqun Zhao,*, Guangchun Wang, Ramana V. Grandhi, Die cavity design of near flashless forging process using FEM-based backward simulation, Journal of Materials Processing Technology 121 (2002) 173–181.*
8. *Victor Vazquez, Taylan Altan, Die design for flashless forging of complex parts, Journal of Materials Processing Technology 98 (2000) 81-89.*
9. *T.Stolarski, Y.Nakasone, S. Yoshimoto, Engineering Analysis with Ansys Software, Buttworth-Heinemann, 2006.*
10. *Badawy, A.A., Raghupathi, P.S., Kuhlmann, D.J. and Altan, T. 1985. Computer-aided design of multistage forging operations for round parts. Journal of Mechanical Working Technology 11(3): 259-274.*
11. *Castro, C.F., António, C.A.C. and Sousa, L.C. 2004. Optimization of shape and process parameters in metal forging using genetic algorithms. Journal of Materials Processing Technology 146(3): 356-364.*
12. *Duggirala, R., Shivpuri, R., Kini, S., Ghosh, S. and Roy, S. 1994. Computer aided approach for design and optimization of cold forging sequences for automotive parts. Journal of Materials Processing Technology 46 (1- 2): 185-198.*
13. *Falk, B., Engel, U. and Geiger, M. 1998. Estimation of tool life in bulk metal forming based on different failure concepts, Journal of Materials Processing Technology 80- 81602-607.*
14. *Hsu, Q. C. and Lee, R.S. 1997. Cold forging process design based on the induction of analytical knowledge, Journal of Materials Processing Technology 69(1-3): 264-272.*
15. *Hu, Z.M., Brooks, J.W. and Dean, T.A. 1999. ThreeDimensional Finite Element Modelling of Forging of a Titanium Alloy Aerofoil Sectioned Blade, Transactions of the ASME, 366 / Vol. 121.*
16. *Hussain, P.B., Cheon, J.S., Kwak, D.Y., Kim, S.Y. and Im, Y. T. 2002. Simulation of clutch-hub forging process using CAMP form. Journal of Materials Processing Technology 123(1): 120-132.*
17. *Im, C.S., Suh, S.R., Lee, M.C., Kim, J.H. and Joun, M.S., 1999. Computer aided process design in cold-former forging using a forging simulator and commercial CAD software. Journal of Materials Processing Technology 95(1-3): 155-163.*

18. *Ishikawa, T., Yukawa, N., Yoshida, Y., Kim, H. and Tozawa, Y. 2000. Prediction of Dimensional Difference of Product from Tool in Cold Backward Extrusion, CIRP Annals Manufacturing Technology 49(1): 169-172.*
19. *Kim, D.J., Kim, B.M. and Choi, J.C. 1997. Determination of the initial billet geometry for a forged product using neural networks. Journal of Materials Processing Technology 72(1): 86-93.*
20. *Kim, Y.S., Son, H.S. and Kim, C.I., 2003. Rigid–plastic finite element simulation for process design of impeller hub forming, Journal of Materials Processing Technology 143-144 (20) 729-734.*
21. *Lee, R.-S., Hsu, Q.-C. and Su, S.L. 1999. Development of a parametric computer-aided die design system for cold forging. Journal of Materials Processing Technology 91(1-3): 80-89.*
22. *Lee, Y. S., Lee, J. H., Choi, J. U., Ishikawa, T. 2002. Experimental and analytical evaluation for elastic deformation behaviors of cold forging tool. Journal of Materials Processing Technology 127 (1): 73-82.*
23. *Meidert, M., Knoerr, M., Westphal, K.. and Altan, T. 1992. Numerical and physical modelling of cold forging of bevel gears. Journal of Materials Processing Technology 33 (1-2):75-93.*
24. *Natsume, Y., Miyakawa, S. and Muramatsu, T. J. 1989. Fatigue abstract analysis on the fracture surface and cold forging die set using the x-ray fractography, Soc. Mater. Sci., Jpn. 38 (429): 612–616.*
25. *Oh, S.I., Wu, W.T. and Tang, J.P., 1992. Simulations of cold forging processes by the DEFORM system, Journal of Materials Processing Technology 35 (3-4): 357-370.*
26. *Ohashi, T., Imamura, S., Shimizu, T. and Motomura, M. 2003. Computer-aided die design for axis-symmetric cold forging products by feature elimination, Journal of Materials Processing Technology 137(1-3) 138-144.*
27. *Petersen, T. and Frederiksen, P.S. 1994. Fillet design in cold forging dies, Computers & Structures 50(3): 393-400.*
28. *Qin, Y., Balendra, R. and Chodnikiewicz, K.. 2000. A method for the simulation of temperature stabilisation in the tools during multi-cycle cold-forging operations. Journal of Materials Processing Technology 107 (1-3): 252-259.*
29. *Song, J. H., Im, Y. T. 2007. Process design for closed-die forging of bevel gear by finite element analyses, Journal of Materials Processing Technology 192-193 1-7.*
30. *Xu, W.L. and Rao, K.P. 1997. Analysis of the deformation characteristics of spike-forging process through FE simulations and experiments. Journal of Materials Processing Technology 70 (1-3): 122-128.*