International Journal For Technological Research In Engineering
Volume 4, Issue 10, June-2017 *ISSN (Online): 2347 - 4718*

ANALYSIS OF NEW METAL FORMING PROCESS USING CERAMIC AS DIE MATERIAL

Ajit Surve
Assistant Professor, Maharashtra Academy of Naval Education and Training,
Loni Kalbhor, Pune-412201

Abstract:* A tool steel is amostly used material for thedies in hot working processes for non-ferrous material. As the temperature, stresses and deformation are high, in the die material; defects like creeps observed. The cracks get developed due to heavy forces and have low die life. The alternate solution for the problem is the ceramic dies, which can withstand the high temperature, and rigid. The high-temperature stability of these materials made it suitable for dies. This paper explains about new suggested hot cum cold-working process for shaping ferrous material using ceramic die. It is not easier to understand the flow pattern of the material passing through the dies. The process variables like the temperature of the billet, cooling system temperature and current passing through billet controls the last structure and properties of the extruded ferrous material. The software "ANSYS" used to get the initial data and a mathematical model would be obtained to calculate the change in the pulling load without considering the effect of the current and temperature of the billet. The concept of mechanics, metallurgy, and nanotechnology are the base for this search. The methods and techniques idealized in this seminar could be used for 3D printing of ferrous and non-ferrous metals.

Keyword: Steel, Ferrous, Drawing, Ceramic, Roller etc.

I. INTRODUCTION

A. Mechanical working of metals

The chip less processes or mechanical working of metals saves the time and wastage. During the processes, the structure of the material changes. Depending on the temperature the metals is under recovery, recrystallization or grain growth condition. The elasticity and plasticity largely get affected by temperature, diffusion, and grains formed. [Fig.1]

The various effects of mechanical working of the metals are,

- Shape changes, deformation occurs, length changes, mass flow rate stay constant.
- Metals are polycrystalline [composed of grains] and in unstrained condition grains are equiaxed and structure is isotropic.
- As the metals deforms, grains get elongated, mechanical properties are directional and structure is anisotropic.
- Polycrystalline ferrous metal composed of two ferrite and cementite subjected to different deformation and mostly ce-mentite which is hard gets failed first. The orientation is as shown in fig. 2.[1]

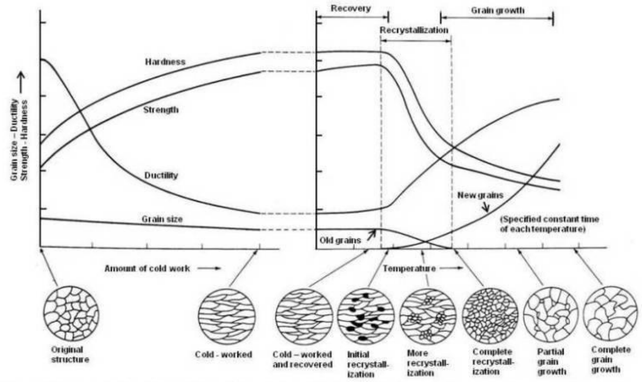


Fig. 1. Recovery, recrystallization and grain growth

- At high deformation, the ferrous metal structure appears fibrous, grains elongated beyond elastic limit and loses their individual characteristics.
- Due to deformation mechanical property changes as shown in fig. 1.[2]
- Nucleation effect in cold work due to excessive work occurs. The heat generated diffuses the atoms and due to which change in grain structure occurs. The pile up of the dislocation at the grain boundary makes the metal hard.
- As the hot working done above recrystallization temper-ature, it deform the grains and followed by instantaneous recrystallization. So the effect of deformation on structure and properties is therefore instantly removed. But in prac-tice the deformation is instantaneous, but recrystallization need time. Hot deformation slowed down to allow complete recrystallization.[1], [3], [2]

Take the time delay advantage, to change the temperature of the billet. The ferrite recrystallization temperature range is 728^0C to 910^0C and the cementite recrystallize at 728 ^{0}C to 1130 ^{0}C depending on carbon percentage. The cementite as it crystallized first stops the equiaxed grains and structure becomes anisotropic. So control over the phase formation and carbon percentage is required.

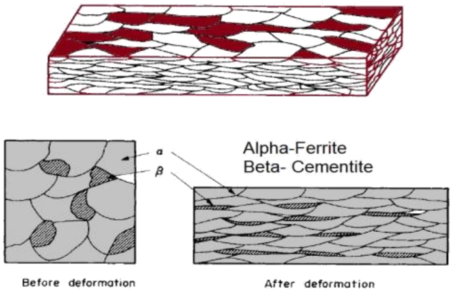


Fig. 2. Effect of mechanical working on ferrous metal

- By controlling the cooling rate it is possible to get the pearlitic structure. Cartwright and Dowding investigated this problem and suggested ideal finishing and coiling tempera-tures for modern steel-strip mills which would produce small equiaxed grains of ferrite with finely dispersed cementite.[1]
- Fig. 3 [1] taken from Cartwright and Dowding's paper focuses on the Effects of finishing and coiling temperatures on the structure of quenched and coiled low-carbon steel strip. [1]

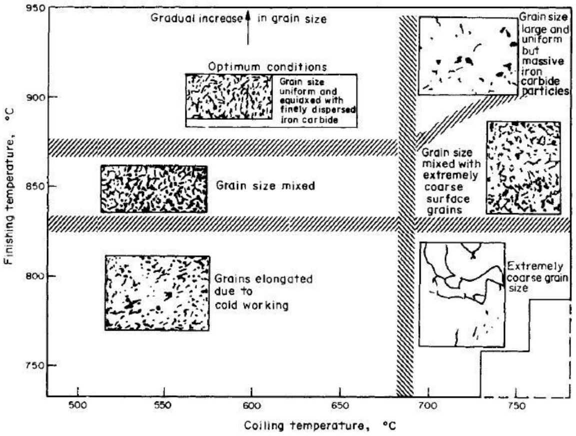


Fig. 3. Effect of finishing and coiling temperatures on the structure of quenched and coiled low-carbon steel strip
Source:[1]

B. Deformation process

By deforming the material, it shaped easily in one stroke without chip formation. Casting is time-consuming and requires skill. Deformation of metal depends on its plasticity. Plasticity of the metals studied. The force, stress, and elongations calculated and the metals could be pushed in certain directions to make the required shapes. The pull/push force applied by the tool. The type of the tool and method of metal flow classifies industrial processes as Deep drawing, Extrusion, Forging, wire drawing etc. The another way of classifying the deformation process is Hot and cold-working. Rolling, forging and extrusion could be hot worked and others are cold worked. Another way based on the deformation occurs. This was first investigated by Siebel in 1933. This method of classification is useful in predicting the properties expected in the deformed metal, but it is not widely used.The fourth way of classification based on stress developed in metals during deformation.Based on the applied system [whether Uniaxial tensile, Uniaxial compressive or biaxial tensile] given three categories. Indirect compression-wire drawing and deep drawingDirect Compression-forging, rolling and extrusion and biaxial tensile-stretchingMost of the recent work done by various scientist and Ph.D. scholars, based on the improving the already existing processes by taking into account the various factors which are effecting on the mechanical working of the metals.

C. Overview

The various research papers and literature explain the al-ready developed processes and improvement in the existing processes. Some of them tried to use ceramic dies for non-ferrous metals. This paper explains the idea to develop a new process based on combinations of some old concepts and new findings for mechanical working of ferrous metals.The concept based on using ceramic die and controlling tem-perature and current to keep up the proper micro constituents and reducing the pulling force, stresses to meet good surface finish and quality of drawn product. A 3D printing of ferrous would be based on the same technique. Fig. 4 and fig. 5 explains the process carried out.

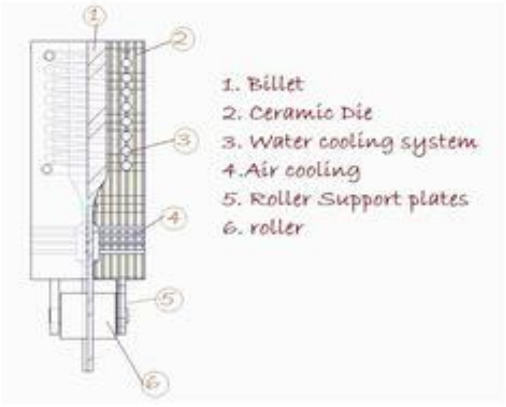


Fig. 4. New metal forming process

The material poured in the semisolid or liquid form and coming out as a solid form. The high current pulses and cooling system will take care of phases of ferrous material so that no breaking stress will get developed. The Pulling rollers apply the force so that the material pulled on the die.

The advantages will be

- Ceramic is a refractory material so that high heat resistant.
- Less wear.
- Crack formation due to creeping gets reduced.
- Surface finish will be improved.

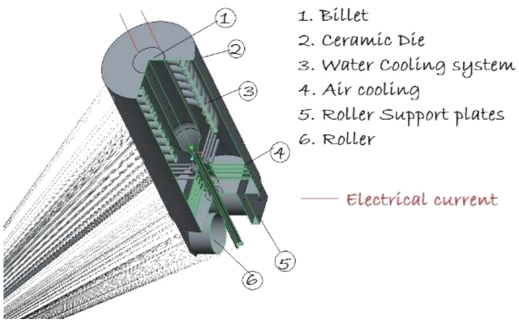


Fig. 5. Sectional view of new metal forming process

- Size control is possible.
- Die economy.
- The various heat treatments are possible.
- 3D printing is the successful process for ABS polymers. The new metal forming process is a step towards metal 3D printing.

II. RELATIONS BETWEEN PARAMETERS

A. Basic terms

The various terms and abbreviations used

Stress[ ]- The metal subjected to tensile stress, localized compression occurs at die interface.

Strain[ ] - the metal elongated, its length changes (dl). The strain rate and stress rates could be controlled by pulling load, current and temperature.

Pulling Load [P]- The load applied to pull the material through the die.

Balancing Force [Fi] - As per D'Alemberts Principle for accelerating component.

Other terms like mass (m), acceleration (a) etc. with usual meanings.

B. Current

The current passed through the material increases the rate of diffusion and temperature, which will effect on the stress and strain of the metal.

$I \propto JT \propto \sigma\epsilon$, I= $f(JT(\sigma\epsilon))$

Work done = VI = m.Cp(δ T)

For steady state diffusion

J=DA $\frac{dT}{dx}$, Where $\frac{dT}{dx}$ is the concentration gradient.

A relation between diffusion and Flow stress modelled or Hall patch equation might be used to calculate yield stress value,

$$\sigma_y = \sigma_0 + \frac{k}{\sqrt{d}}$$

The grain size affected by diffusion and temperature.

C. Cooling system

Temperature increases the rate of diffusion and soften the material so more deformation is possible, but also reduces the value of yield point stress.So to keep up the value of flow stress at the die section it is necessary to lower the value of temperature and allowed the deformation at an optimum flow stress value so that the breaking of the material will not occur.It is so arranged that the ceramic die strength would not be subjected to higher localized stresses.

D. Stress, Pulling Force and Power

The temperature effect on the yield strength of steel. The process assumed like a wire drawing, but under gravity. The weight of the material assists the process and the acceleration assumed 'a'. The power requirement in the beginning is more.

E. Reduction assumed

In the traditional process, the greatest reduction in steel is 63% without considering friction. So with friction, largest reduction assumed up to 50%. The die divided into three sections. In each section the reduction is different dependent on current supplied, diffusion and temperature of billet. Values given in the Table 1, shows the various reduction ratios at various sections. [R is the reduction ratio]

III. MATHEMATICAL FORMULATION FOR CALCULATINGSTRESSES AT VARIOUS SECTION

The basic equation given in John Harisbook[1] modified. A centrifugal force applied vertically as the process aligned vertical.

A. Stress at various sections

Refer fig.6 Deformation in this operation defined by reduction in area

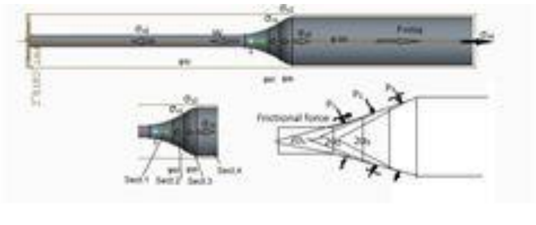


Fig. 6. Various sections, forces assumed on the billet

reduction in area

$A_1 = \frac{\pi D_1^2}{4}$ and $A_2 = \frac{\pi D_2^2}{4}$

Then the reduction is given by,

$$R = (\frac{A_1 - A_2}{A_1})*100\% = (\frac{\pi D_1^2 - \pi D_2^2}{\pi D_1^2})*100\% = (\frac{D_1^2 - D_2^2}{D_1})*100\% \quad (1)$$

The pulling load for the metal is dependent on reduction (R). The breaking or limit will be when pulling load equals the breaking load (PL=BL).

$$PL = \sigma_1 . A_2 \text{ and } BL = Y . A_2$$

The pulling load for the metal is dependent on reduction (R). The breaking or limit will be when pulling load equals the breaking load (PL=BL).

PL = $_1$:A$_2$ and BL = Y:A$_2$

TABLE I: REDUCTION ASSUMED

Section	D1	D2	r	R=1-r
Section 1	200	110	0.3	0.7
Section 2	110	65	0.35	0.65
Section 3	65	50	0.6	0.4

Where, 1 is yield stress of metal and Y is the ultimate stress of the metal.

$$\text{Volume} = AL$$
$$dW = \sigma_0.V.\frac{dl}{l}$$
$$W = \sigma_0.V.ln(L_2/L_1)$$

$$\text{Let } r = \frac{A_1}{A_2} = \frac{L_2}{L_1}$$
$$P = \sigma_0.ln(r)$$
$$\sigma_1 = Y.ln(r),\ r = \frac{A_1}{A_2}$$
$$\sigma - 1 = Y.ln(\frac{1}{1-R})$$
$$\text{When } \sigma_1 = Y \text{ and } R = R_{max}, \text{ breaking Occurs}$$

$$\frac{\sigma_1}{Y} = ln(\frac{1}{1-R_{max}}) = 1$$

Maximum Reduction possible =63 % without considering friction

In Practice let it be 50% maximum reduction per pass with friction.[1]

- Assumptions
- Metal is not work harden
- Die angle is constant
- Tresca's yield criteria is applied
- Principle stresses are P and x
- Internal distortion of metal is ignored.
- The metal deformation is elastic and plastic only, no strain hardening is allowed.[1]

Applying the concept to circular section,

$$\text{For steel; } \alpha = 3\,\text{deg}, \mu = 0.15, R = R_m, \sigma_{x1} = \sigma_{x0} \text{ [1][3]}$$

$$\text{Using equation,[1] } (\frac{\sigma_(xa)}{\sigma_0}) = (\frac{1+B}{B}).[1-(1-R_m)^B]$$

$$R_m = 38\%$$

As the area is large and die angle is small, less reduction ispossible.Refer fig. 7

A small elementary thickness dx considered at the distancex from the origin of cone angle 2_1 The drawing stressacting on this side is _x1. Let the pressure P is acting normalto the die surface, the metal moves with acceleration "a"m=s2, and weight is 'w'. Refer fig. 8

The frictional force, D'Alembert inertia force and weight ofthe metal are other forces.

The equilibrium equation is,

$$(\sigma_x + d\sigma_x).(\frac{\Pi}{4}).(D + dD)^2 - (\sigma_x).(\frac{\pi}{4}).(D^2) +$$

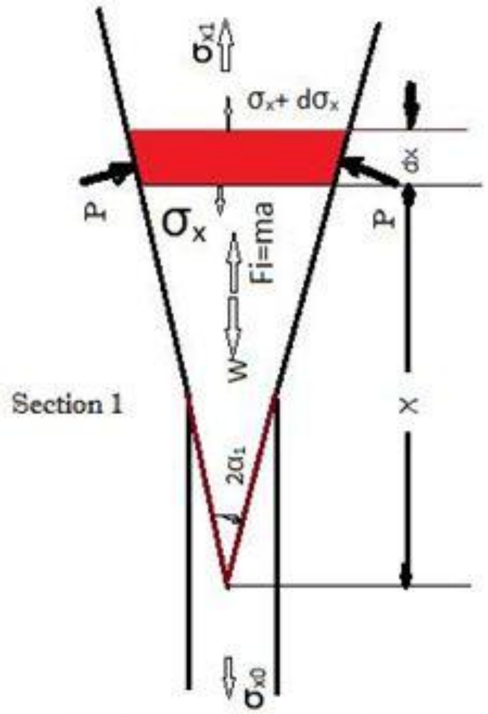


Fig. 7. Various forces acting at section 1

$$P.\pi D.(\frac{dx}{cos\alpha_1}).(sin\alpha_1)$$
$$+\mu.P(\pi D\frac{dx}{cos\alpha_1}).(cos\alpha_1) - W + F_i = 0$$

$$(\sigma_x + d\sigma_x).(\frac{\Pi}{4}).(D + dD)^2 - (\sigma_x).(\frac{\pi}{4}).(D^2) + P.\pi D.(\frac{dx}{cos\alpha_1}).(sin\alpha_1) + \mu.P(\pi D\frac{dx}{cos\alpha_1}).(cos\alpha_1) - \rho.g.dx[\frac{\pi}{12}(3D^2 + 3DdD)]$$
$$+\rho.g.a.dx[\frac{\pi}{12}(3D^2 + 3DdD)] = 0$$

Simplifying,

$$\frac{\sigma_x.D.dD}{2}+\frac{D^2.d\sigma_x}{4}+PDdxtan\alpha_1+\mu PDdx-\rho.g.(\frac{\pi}{12}).[3D^2+3DdD]dx \quad (2)$$

Dividing by D, multiply by 4 and replacing,

$$dD = 2.dx.tan\alpha_1$$

$$2.\sigma_x.dD + D.d\sigma_x + 4.PdD.tan\alpha_1 + 4.\mu P.dD.cot\alpha_1$$
$$-\rho.g.dx[D + dD] + \rho.g.dx[D + dD].a = 0$$

$$D.d\sigma_x + 2.\sigma_x.dD + 2.P.dD + 2.\mu P.dD.cot\alpha_1$$
$$-\rho.g.(\frac{dD}{2}).[D + dD].cot\alpha_1] + \rho.(\frac{dD}{2}.[D + dD].cot\alpha_1].a = 0$$

$$2D.d\sigma_x + 4.\sigma_x.dD + 4.P.dD + 4.\mu P.dD.cot\alpha_1 - \rho.g.(dD).[D + dD].cot\alpha_1] + \rho.(d).D.[D + dD].cot\alpha_1.a = 0$$

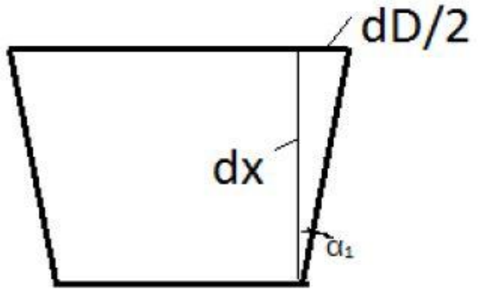


Fig. 8. Section Angle

$$2.D.d\sigma_x+[4\sigma_x+4P+4\mu.P.cot\alpha_1].dD-\rho.g.dD.cot\alpha_1.D+\rho.g.dD.cot\alpha_1.D.a=0$$

$$2.D.d\sigma_x + [4\sigma_x + 4P + 4\mu.P.cot\alpha_1].dD = \rho.g.dD.cot\alpha_1.D.(1-a)$$

$$D.\tfrac{d\sigma_x}{dD} + (2\sigma_x + 2P + 2\mu.P.cot\alpha_1) = \rho.g.cot\alpha_1(\tfrac{1-a}{2}).D$$

$$\frac{d\sigma_x}{dD} + \frac{2\sigma_x + 2P + 2\mu.P.cot\alpha_1}{D} = \rho.g.cot\alpha_1(\frac{1-a}{2}) \quad (3)$$

At the point of yielding using Tresca's Yield point criteria, $\sigma_x = \sigma_0 - P$ so that,$P = \sigma_0 - \sigma_x$

$$\frac{d\sigma_x}{dD} - \frac{2\mu.P.cot\alpha_1}{D}.\sigma_x = \rho.g.cot\alpha_1(\frac{1-a}{2}) - \frac{2\sigma_0}{D}.(1+\mu) \quad (4)$$

The equation '4' is a linear differential equation of first order.

$$IF(integratingfactor) = e^{\int \frac{-2\mu.cot\alpha_1}{D}.dD} = D^{(-2\mu.cot\alpha_1)} \quad (5)$$

$$\sigma_x(IF) = \int Q.(IF).dD + C$$

$$\sigma_x = \rho.g.\tfrac{D}{1-2\mu.cot\alpha_1}.cot\alpha_1.(\tfrac{1-a}{2}) + \sigma_0(1+\mu).\tfrac{1}{\mu.cot\alpha_1} + C.D^{2\mu.cot\alpha_1}$$

Let $B = \mu.cot\alpha_1$

$$\sigma_x = \rho.g.\frac{D}{1-2B}.cot\alpha_1.(\frac{1-a}{2})+\sigma_0(1+\mu).\frac{1}{B}+C.D^{2B} \quad (6)$$

Equation 6, is the governing equation stress in various sections.

IV. APPLYING EQ.6 AT VARIOUS SECTIONS

Section 3: Refer to fig. 9, $\sigma_{x3} = 0$ at $D = D_3$ and $B = \mu cot\alpha_3$ Gives,

$$C = \frac{1}{(D_3)^{2B}}.[\rho.g.cot\alpha_1.(\frac{a-1}{2}).(\frac{D_3}{1-2B})] + \frac{\sigma_0(\mu-1)}{B} \quad (7)$$

Equation for stress is,

$$\sigma_x = \rho.g.cot\alpha_3.\frac{D}{1-2B} + \frac{\sigma_0(1-\mu)}{B} + C.(D)^{2B} \quad (8)$$

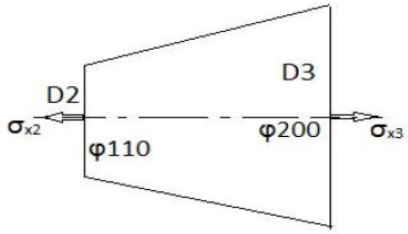


Fig. 9. Section 3

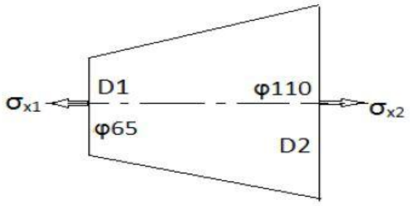


Fig. 10. Section 2

Section 2:

Refer to fig. 10, $\sigma_x = \sigma_{x2}$ at $D = D_3$ and $B = \mu cot\alpha_2$ Gives,

$$C = \frac{1}{(D_2)^{2B}}.[\rho.g.cot\alpha_2.(\frac{a-1}{2}).(\frac{D_2}{1-2B})] + \frac{\sigma_0(\mu-1)}{B} \quad (9)$$

Equation for stress is,

$$\sigma_x = \rho.g.cot\alpha_2.\frac{D}{1-2B} + \frac{\sigma_0(1-\mu)}{B} + C.(D)^{2B} \quad (10)$$

Section 1:

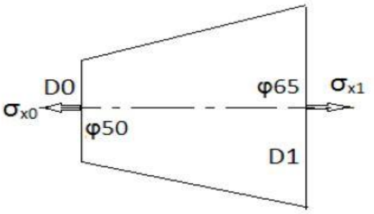


Fig. 11. Section 1

Refer to fig. 11, $\sigma_x = \sigma_{x1}$ at $D = D_1$ and $B = \mu cot\alpha_1$ Gives,

$$C = \frac{1}{(D_1)^{2B}}.[\rho.g.cot\alpha_1.(\frac{a-1}{2}).(\frac{D_1}{1-2B})] + \frac{\sigma_0(\mu-1)}{B} \quad (11)$$

Equation for stress is,

$$\sigma_x = \rho.g.cot\alpha_1.\frac{D}{1-2B} + \frac{\sigma_0(1-\mu)}{B} + C.(D)^{2B} \quad (12)$$

A. Calculation Table

The following table 2,3 and 4 shows the calculations for stresses at various sections using given values for steel.

B. Pulling Load

Referring table 4, The stress value at 50mm dia. is 25.83

N=mm^2

Area = $_4$ 50^2 = 1963.5 mm^2

Pulling Load = Area x stress

1963:5 25:83

50717N
50:717KN

V. POWER REQUIREMENT

Power=force x velocity
50:717 0:25
12:679KW
17hp

VI. RESULTS

The billet deformation processed at 22 ^{0}C is as shown in the fig. 12

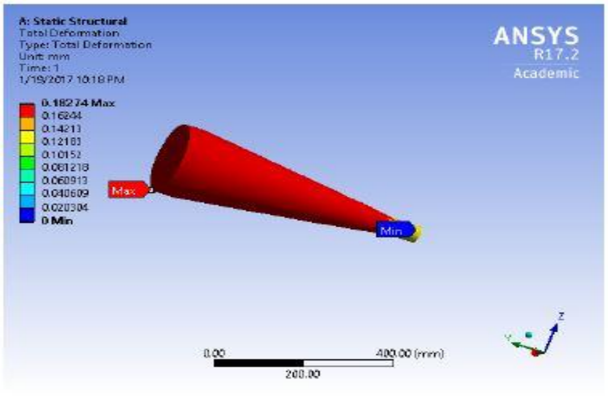


Fig. 12. Billet deformation at 22 deg temperature

The analysis of billet and other structural components using ANSYS software. 1. Static structural for stresses and deformation

2. Steady state thermal for varying convention rate.

The material used is ” Structural steel” with standard mechanical properties for both die and billet.

A. Static structural

The inlet conditions are, Pulling force 50717N and temperature is varying along the length. At the 200mm dia. temperature is 1000 ^{0}C and at 50mm diameter temperature is 300 ^{0}C. Refer fig. 13 and 14

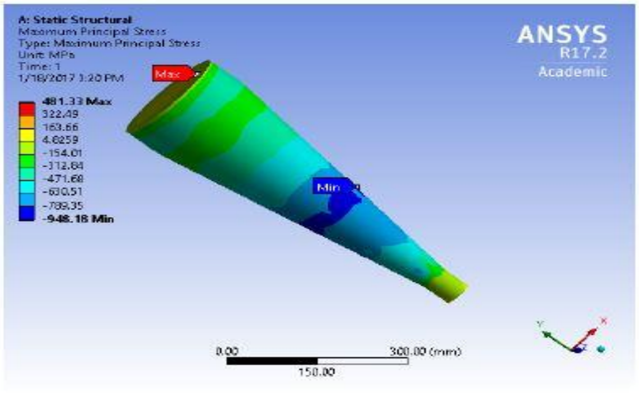


Fig. 13. Maximum Principle stress

The elongation, stress developed and equivalent elasticstrain are as given in the table 5.

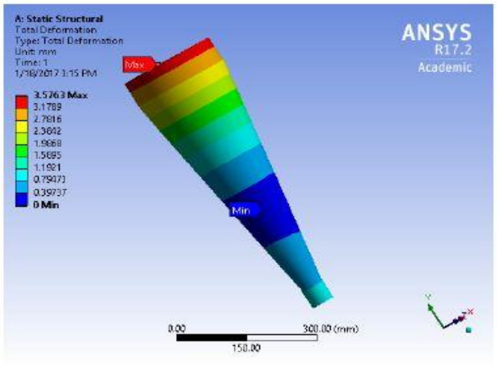


Fig. 14. Deformation when temperature varies from 300-1000 deg

The plastic deformation occurs at some point, but not reaching to the maximum or breaking strain value. As the temperature varied in the different sections, the deformation is also varies.

2. Steady state Thermal

Variation of temperature along the length is from 300 ^{0}C to 1000 ^{0}C is as shown in fig. 15

The temperature variation observed for various cooling rates. The variation in temperature also effects on the total deformation of billet.

The variation in temperature controlled by the current passing through the die.

Along the length the temperature variation less or more will change the deformation and final quality of the product.

B. Future study

How the current effects on temperature and deformation? Developing relation between current, diffusion andtemperature.

TABLE II
ASSUMED VALUES

D3 in meter	0.2	μ	0.15
D2	0.11	σ_{03} in N/m^2	10000000
D1	0.065	σ_{02}	2585000000
D0	0.05	σ_{01}	11045000
α_3	0.2213	ρ	7850
α_2	0.1322	L3 in meter	0.2
α_1	0.05356	L2	0.17
a in m/s^2	0.5	L1	0.14

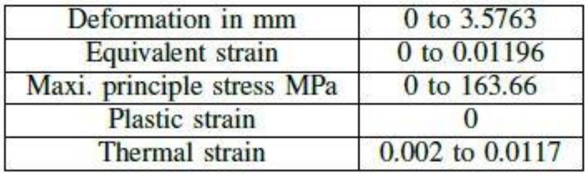
TABLE III
VALUES OF YIELD STRESS OF STEEL AT DIFFERENT TEMPERATURE

Temperature	σ_0	Temperature	σ_0
100	235000000	700	54000000
200	235000000	800	25850000
300	235000000	900	13000000
400	235000000	1000	10000000
500	183000000	1100	7000000
600	110450000	1200	3500000

TABLE IV
THE CALCULATED VALUES FOR STRESSES AT VARIOUS SECTIONS

B3	0.667	C3	-1.085E+8	$\sigma_x 2$ in MPa	7
B2	1.1275	C2	-2.83E+09	$\sigma_x 1$ in MPa	13.54
B1	2.7975	C1	-1.47E+14	$\sigma_x 0$ in MPa	25.83

TABLE V
PROPERTIES TESTED FOR BILLET AT 300-1000 DEG



Deformation in mm	0 to 3.5763
Equivalent strain	0 to 0.01196
Maxi. principle stress MPa	0 to 163.66
Plastic strain	0
Thermal strain	0.002 to 0.0117

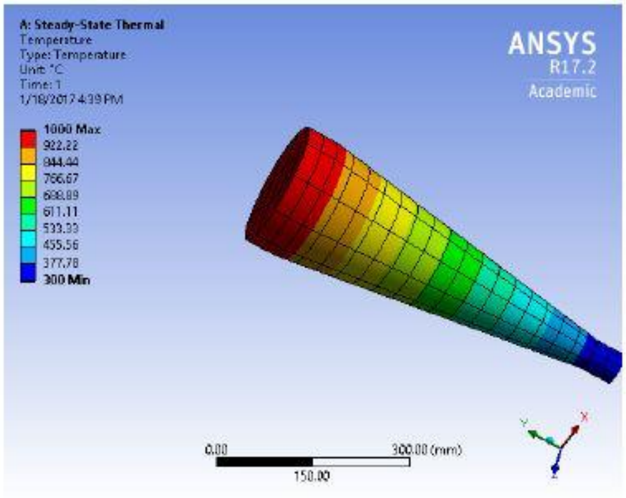


Fig. 15. Temperature variation in billet

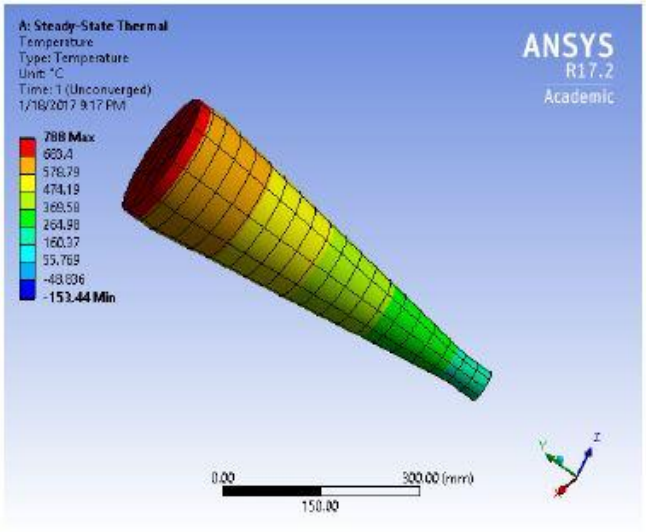


Fig. 16. Convention 1

Use of Laser Techniques for heating metals.

Study related to the temperature, stress variation control and quality of finished product etc. is required.The methods and techniques could be used for 3D printing of ferrous material with few modifications.

VII. LIMITATIONS

1. Material for die: The various advantages of ceramics are higher in strength, fracture toughness, hardness, wear resistance, frictional behaviour, heat resistance, non-magnetic, thermal conductivity, corrosion resistance, excellent surface finish (0.0055 m Ra), modulus of elasticity like steel, thermal expansion coefficient like cast iron.Whereas limitations are

- Ceramics are weak or brittle.

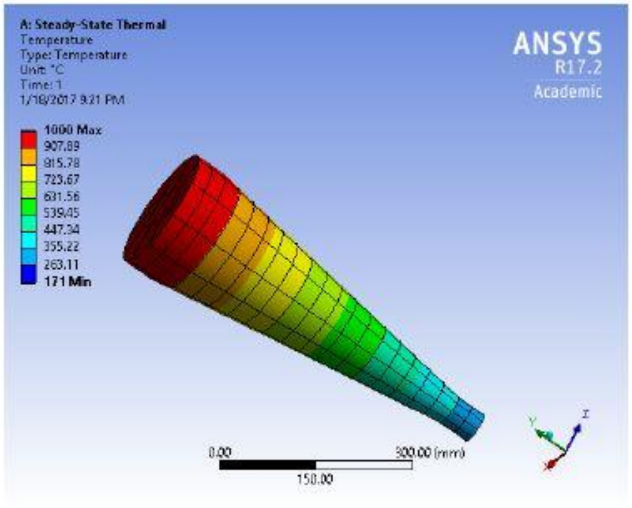


Fig. 17. Convention 2

- Dimensional tolerances difficult to control during processing.
- Weak in tension so only compression stresses allowed in die.
- Poor shock resistance so that we can’t use it in extrusion.
- Get cracked under heavy impacts.
- The practical difficulty in using oxide ceramic, at high-temperature chances of oxidation are more.
- For the die, a material which is tough as well as hard needed. Nanotechnology material or ceramic[CMC] based composite material could be utilized.

VIII. FUTURE WORK

1. How to initiate the process? 2. Finding the effect of current on diffusion 3. Relation between current, diffusion, friction and stress.

IX. CONCLUSION

Invented non-chip forming processes were developed and improved, but most of the processes use tool steel as the material for die with disadvantages of creep and crack on the walls of the die. This paper explains a new process to use ceramic as die material and required changes in the process. If the temperature is kept constant at 22 0C, the maximum deformation possible is 0.18 mm. But the deformation 0.4 mm to 3.57 mm is possible with billet subjected to varying temperature. The pulling load calculated by using equilibrium conditions and D'Alembert's principle. A mathematical equation is derived for calculating pulling load.By using forced convection and current it is possible to control the temperature of billet in the newly suggested process.The process combines wire drawing and casting process but separated from it as the temperature varied as per requirement. The stresses developed are the compressive type and not exceeding beyond the strength of ceramic so that the ceramic dies can be used suitably. The high-temperature resistance is added advantage of ceramic.In future, the effect of the current would be studied. The non-conventional processes like EDM are base processes.Still more studies related to the temperature, stress variation control and quality of finished product is required.The methods and techniques could be used for 3D printing of ferrous material with some modifications.

ACKNOWLEDGMENT

My special appreciation goes to my family - my family has been a consistent source of love, care, support and affection, a person could ever ask for.I would like to thank administrative and technical staff members of Principal, Academic dean and technical staff of the Maharashtra Academy for Naval Education and Training, LoniKalbhor, Pune who have been kind enough to advise and help in their respective roles. I thank all those who are directly or indirectly involved in shaping up of this research work.Finally, I thank the almighty God, without the blessings of whose, nothing would be possible.

REFERENCES

[1] J. N. Harris, Mechanical working of materials, theory and practice. Pergamon Press, First edition 1983.

[2] W. C. et al., Material science and Engineering: An introduction. John Wiley and Sons, 2009.

[3] J. George E. Dieter, Mechanical Metallurgy. McGraw-Hill book company New York, Toronto, and London, 1961.

[4] L. O. MalgorzataRosochowska, AndrzejRosochowski, "Finite element analysis of cold forward extrusion of 1010 steel," The annals of "Dunarea de jos" University of Galati Fascicle V, Technologies in machine building, ISSN 1221- 4566, 2009.

[5] C. Xu and et al, "Compositional design of ceramic extrusion die materials based on the residual stress and analysis in die manufacturing process," Advanced Material Research, ISSN:1662-8985, vol 291-294, pp 1709-1712, 2011.

[6] A. Krawiec and et al., "Numerical analysis of influence lubrication conditions on the filling pattern in a complex process of extruding particular high melting materials," Metallurgy and foundry engineering-vol.38, No.1, 2012.

[7] S. Hansson, "Simulation of stainless steel tube extrusion," Ph.D. disserta-tion, Division of Material Mechanics Department of Applied Physics and Mechanical Engineering Lulea University of technology Lulea, Sweden, 2006.

[8] L. C. D. Jonghe and M. N. Rahaman, Handbook of advanced ceramic.

[9] www.asminternational.org. (2000) Fundamentals of extrusion, aluminum extrusion technology.

[10] H. M. Swann, "Extrusion plant for non-ferrous metals," Victorian Institute of engineers, 1949. [Online]. Available: http://hdl.handle.net/11343/24908

[11] M. Revised by MuraliBhupatiraju, A. A. Robert Greczanik, and Manufacturing, Cold Extrusion, S. Semiatin, Ed. ASM Handbook, 2005, vol. Volume 14A: Metalworking: Bulk Forming p405-418.

[12] G. X. et al, "Optimization of the technology of wire drawing based on finite element modeling," Modern applied science, 2009.

[13] R. L. Antonio Zomp, "Advances in wire drawing process by theoretical and numerical analysis," 2008.

[14] R. B. Gifford, "An investigation of product quality modification capabil-ities during wire drawing," Ph.D. dissertation, Lehigh University Lehigh Preserve, 2000.

[15] H. J. French, "Effect of temperature, deformation and rate of loading on the tensile properties of low-carbon steel below the thermal critical range," Technological papers of bureau of standards, vol. vol.16, 1992.

[16] L. de Mcanique de Lille et al, "Temperature effects on wire-drawing process: Experimental investigation," International Journal of Material Forming, 2009.

[17] M. Z. Viktor Tittel, "A comparison of die geometry in the drawing process," Faculty of materials science and technology in Trnava, Slovak university of technology in Trnava, Slovak university of technology in Bratislava, 2009.

[18] K. F. Y. et al [4], "A research on electro plastic effects in wire drawing process of an austenitic stainless steel," ScriptaMaterialia, 2001.

[19] A. P. et al., "Effect of high speed drawing on properties of high carbon steel wires," International Journal of Modern Engineering Research (IJMER), vol. Vol.2,Issue-2, pp. 209–214, 2012.

[1] [3] [4] [5] [6] [7] [8] [9] [10] [11] [2] [12] [13] [14] [15] [16] [17] [18] [19]