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EFFECT OF HEAT TREATMENT ON DEEP DRAWING OF STAINLESS STEEL 304 FOIL OF THICKNESS 0.1MM

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ABSTRACT

The influence of heat treatment thereby hardness on flow ability of austenitic Stainless steel 304 foil of thickness 0.1mm was analyzed with Deep drawing process at calculated force. The standard electrical fuse cap having a round cup shaped was taken as a reference product for this work. The deep drawing of some materials having low ductility is very difficult especially for stainless steel having a thickness less than 0.5mm is an industrial challenge. The wrinkle formation in the edges of the product due to less blank holding forces and the tearing of the metal due to low ductility is very difficult to maintain. The ductility mainly affects the limiting draw ratio of the cup shaped product. The main aim of this analysis is to increase limiting draw ratio of the material by improving its ductility with annealing process. The analysis is done to find the cause of the problem and thereby to get a possible best solution theoretically as well as experimentally.

Keyword: Cup shaped, deep drawing, ductility, limiting draw ratio, stainless steel

I. INTRODUCTION

In the present study, the main focus is on the flow behaviour of the material thereby ductility of the material. The material chosen for this work is stainless steel 304 foil of thickness 0.1mm and deep drawing of stainless steel of thickness less than 0.5mm is an industrial challenge. Because of its exceptional properties of corrosion resistant even in environment containing chlorine and good strength, it has wide range of application. It is not a reactive metal and behaves like an inert material so it is widely used in medical field like in the manufacturing of surgical tools. Austenitic stainless steel 304 also used in pipes of chemical plants and other applications that may subject to the conditions of cyclic load [1]. This material can also be recycled easily. The earlier researchers on deep drawing mainly focused on deep cylindrical cups having large height to diameter ratio [2-5] and the materials they used for the research are aluminium alloys, super alloy, carbon steel alloy and stainless steel [6-9]. Deep drawing is an operation of producing cylindrical or shell shaped components in which sheet metal blank is drawn radially into a forming die by the mechanical action of punch. The material experiences a tension as well as compression force. Common shape for deep drawn products include cylinders for aluminium can and cups for blanking pans. Irregular items, such as enclosure covers for truck oil filters and fire extinguishers, kitchen sink are also commonly manufactured by this method.

Table 1: Composition (% by weight) of 304 stainless steel alloy using Atomic absorption spectrometer

Element	Symbol	Value (%)
Carbon	C	0.06
Silicon	Si	0.628
Manganese	Mn	1.03
Phosphorous	P	0.030
Sulphur	S	0.030
Chromium	Cr	18.12
Nickel	Ni	9.44

Table 2: Physical properties 304 stainless steel alloy

Property	Value
Density	$8.00 g/cm^3$
Melting Point	1450^oC
Modulus of Elasticity	193GPa
Electrical Resistivity	$0.072\times10^{-6}\Omega m$
Thermal Conductivity	16.2W/m-K
Thermal Expansion	$17.2\times10^{-6}/K$

Zhengyi Jiang et al. studied about the effects of surface roughness on micro deep drawing of circular cups while considering the size effects [10]. Syed Mujahed Hussaini et al. studied about forming limit diagrams for warm forming of stainless steel 316 [11]. Graham Green et al. investigated on micro deep drawing of stainless steel 304 using flexible tool [12]. Xinkai Ma, Fuguo Li analyzed the forming limit analysis of St 14 steel sheets based on new ductile damage criteria [13]. M. Aparicio et al. experimented with AISI 304 sheet for its corrosion protection by coating melting gel [14]. The stainless steel 304 material characterisation and finite element modelling of cyclic plasticity behaviour has been investigated using a crystal plasticity model, Jiawa Lu et al. [15]. G.P. Zhang et al. studied experimentally about the fatigue strength small scale type stainless steel 304 thin films [16].

In the present study, the ductility of the material was increased by furnace annealing and limiting draw ratio of this thin sheet was compared before and after annealing process. The die set assembly is designed and fabricated using the standard dimension of the electrical fuse cap which is cylindrical in shape. The experiment is done on that die set assembly by providing the calculated force.

II. DESIGN OF DIE SET ASSEMBLY

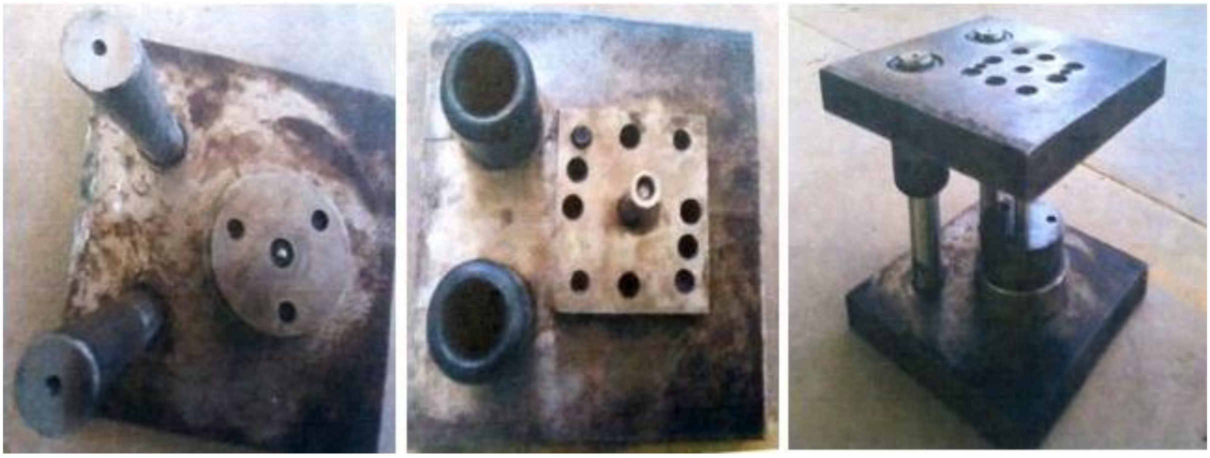
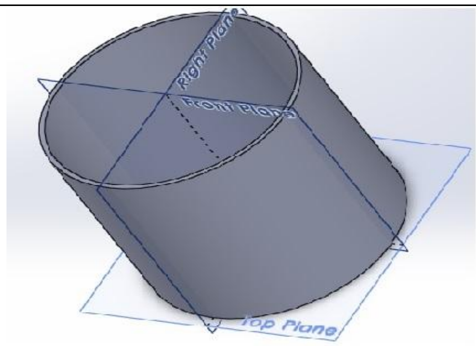


Fig.1 Die set assembly

The standard measured specification of electrical fuse cap. Formulae and assumption used for designing the required die set assembly [17].

Internal diameter of cap, d = 5.2mm Thickness of foil, t = 0.1mm Punch corner radius, r = 4t = 0.4mm Height of the cap, h = 4.5mm Tensile strength of stainless steel 304, σ = 515 MPa Shear strength of material, τ = 215 MPa Draw clearance, C = 1.07t = 0.107mm	
Specification of cup shaped electric fuse cap	Fig.2 Cup shape model using Solid works modelling

2.1 Number of draws

Draw ratio = h/d = 0.8654; since 0.75<h/d<1.5

Therefore, No. of draws = 2

2.2 Blank size (D)

d/r = 13; since 1<d/r<15

Therefore, theoretical blank diameter, $D_{th} = \sqrt{d^2 + 4dh - r} = 10.5836$

Actual blank diameter, $D = D_{th} + \left(\frac{3}{25} \times d\right) = 11.2076\text{mm} \approx 12\text{mm}$

2.3 Sheet width (w)

$w = D_{th} + 2t = 11.4076\text{mm}$

2.4 Drawing force (P)

$P = \pi \times d \times t \times 6\left(\frac{D}{d} - c\right)$; where c is constant to cover friction and bending

=1312.5N; c = 0.6-0.7 for ductile material

2.5 Blank Holder Force (F_b)

F_b = P/3 = 450.83N

2.6 Ironing Force (F_i)

Fi = Fb = 450.83N

2.7 Die Cushioning Force (F_{dc})

Fdc = 20% of (P + F_b + F_i) = 442.83N

2.8 Total Force (F)

F = P + F_b +F_i × FOS + F_{dc} = 2792.24N; Assume Factor of Safety (FOS) = 1.3

2.9. Press Capacity in Tonnage (P_c)

P_c = 0.2792 ton

2.10 Percentage reduction in Blank Diameter

2.10.1 Percentage reduction in first draw,

$P_1 = \left(1 - \frac{d}{D}\right) \times 100\% = 53.7\%$

Since permissible reduction in diameter in first draw is only 50%, therefore 40% reduction is taken for first draw and 15% is for second draw. So the P_1 is taken as 40% and P_2 is 15%.

Using percentage reduction in diameter we can calculate the diameter after each draw and using this we can get the required percentage reduction in diameter in third draw.

Diameter of cup after first draw (d_1) = 6.72mm

Diameter of cup after second draw (d_2) = 5.71mm

Since the required diameter of cup is 5.2mm so using values of d and d_2 we can get the percentage reduction in diameter after third draw P_3.

Percentage reduction in diameter after third draw, P_3 = 8.93%

2.11 Design of die

Blank die size = D = 11.2076mm

Drawing die size = (d-2t) + 1.1t = 5.11mm

2.12 Die block design

From PSGDB for corresponding strip, the die block thickness is 1mm/Kg/mm^2

Cutting perimeter = π × D = 35.21mm

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For corresponding cutting perimeter, the factor to be multiplied is 1.25

Die block thickness = $t \times \tau \times 1.25$ = 26.875mm

Width of the block = 2 × Die block thickness = 53.75mm

Length of die block = Width of die block = 53.75mm

2.13 Design of Punch

Corresponding to strip thickness, the clearance provided to the punch is 0.01mm

Blanking punch size = D – 0.01 = 11.1976mm

Die punch size = d-1.1t = 5.09mm

Height of the punch block = Die block thickness = 26.875mm

Corner radius of punch = 4×t = 0.4mm

III. HEAT TREATMENT OF STAINLESS STEEL 304 FOIL

The sample of dimension 150mm×100mm was heat treated (annealed) in the electric furnace. The sample was heated at the austenitic temperature 925^{o}C in the heat treatment furnace. When the temperature was reached to 925^{o}C, the electric supply was being cut off and the sample was left in the furnace itself for cooling up to 2.5 hrs. The hardness of the sample before and after heat treatment was measured.

IV. HARDNESS TESTING OF FOIL AND MEASUREMENT OF DIMENSION OF PRODUCT

The hardness of stainless steel 304 samples was tested using Vicker hardness testing machine and the hardness value of the sample before heat treatment was measured. The average value was taken after taking five readings and the average value is found to be 436 HV. Then the sample was pressed using the die set assembly but the required draw ratio was not obtained and tearing in the material occurs during second draw. It may happen because of high hardness value and thereby low ductility of the material.

Fig.3 Product before heat treatment of the Foil **Fig.4 Product after heat treatment of foil**

After heat treatment, the hardness value is measured again and five readings were taken. The average value of hardness for the heat treated sample was found to be reduced and it was 186 HV. Again the sample was pressed and the required draw ratio is obtained in this hardness value.

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The height of products drawn was measured using Vernier height gauge with least count of 0.02mm and the diameter was measured using Vernier caliper with least count of 0.02mm and then h/d ratio is calculated.

V. CONCLUSION

From the above experiment, it can be concluded that the hardness of the stainless steel 304 was decreased after heat treatment process thereby increased its ductility and drawability that lead to increase the limiting draw ratio of the material which helped us to get the required depth of the product. The increased limiting draw ratio can be observed through fig.3 and fig.4.The formation of wrinkle at the top edge of the product was observed. The main reason may be the less blank holding force and strain hardening induced in the material during the process. This may be reduced by increasing blank holding force and using warm deep drawing process.

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