LIST OF PUBLICATIONS

A) Publications in International Journals:

1. PAPN Varma, KGK Murti, AVS Raju, 'Forming of Cylindrical components in Warm condition under Deep Drawing Setup using Flow Forming Principle" International Journal of Mechanical Engineering, ISSN No 0974-5823, January-June 2011, Volume 4 ,Issue 1, 27-33

   Status: Paper published

2. PAPN Varma, K. Rakesh Varma, KGK Murti, AVS Raju, and Swadesh Kumar Singh" Mathematical modelling and micro structural studies of excessive ironing of EDD steel in deep drawing setup in Warm conditions" International Journal of Advanced Materials Manufacturing & Characterization, ISSN No 2277-3886,March 2012, Vol 1, Issue ,1 165-172

   Status Paper: Paper Published

B). International Conferences:

P A P N Varma, Swadesh Kumar Singh, et.al "Evaluation of Friction at 200^{0}C and experimental study on the extent of deformation in flow forming of EDD steel using Deep Drawing Setup at International Conference on *Hot forming of steels and Product properties"* conducted by Associazione Italiana Metallurgia, at Grado, Italy during 13-16 Sep 2009

Forming of Cylindrical Components in Warm Condition Under Deep Drawing Setup Using Flow Forming Principle

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ABSTRACT: The present work describes about design, development of equipment required for conducting experiments to study flow forming of metal at different temperatures and at different reduction rates under deep drawing setup. For this, a press with suitable die and punch set was chosen by selecting Inconel-600 material for the dies. In the present paper an effort was made to develop the indigenous setup to carry out flow forming in the deep drawing setup.

Keywords: Flow Forming; Deep drawing; Warm forming.

1. INTRODUCTION

Flow forming is an advanced form of metal spinning. Metal spinning utilizes a relatively thinner piece of starting material than flow forming, and produces the shape of the finished part from a larger diameter starting blank than the largest diameter of the finished part-very similar to deep drawing. No reduction of the wall thickness is contemplated, but is often experienced and is very difficult to control. Flow forming, on the other hand, is based upon a predetermined reduction of the thickness of the starting blank or preforms, a reduction, which is very accurately controlled.

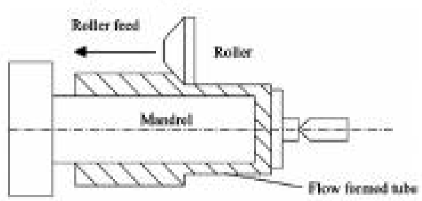

Figure 1: Flow Forming of Tubular Products

In last two decades or so, flow forming has gradually matured as a metal forming process for the production of engineering components in small to medium batch quantities. Due to its inherent advantages such as flexibility, simple tooling and low forming loads, flow forming has enabled customers to optimise designs and reduce weight and cost, all of which are vital, especially in the automotive industries. The flow forming process, including shear forming, which grew out of spinning, is a process whereby the workpiece is rotated while the tool, which rotate about its own axis, may move axially or radially to the axis of rotation of workpiece, manipulating it to the final desired shape. It is most widely used to produce thin walled, high precision tubular products where the tubular workpiece is held onto the mandrel, the material being displaced axially by one or more rollers moving axially along a mandrel, as shown in Fig. 1.

2. WARM FORMING AND RECENT ADVANCEMENT IN THE AREA

Although the deep drawing process of high strength/ low formability metals has an extensive industrial application area, deep drawing at room temperature has serious difficulties because of the large amount of deformations revealed and high flow stresses of the materials (Bolt et al., 2001). Thus; crumples, wrinkles and earings will occur on the product surface because of the anisotropy of the materials. Elevated temperatures decrease the flow stresses and increase the formabilities of the materials and thus deformations become easier. The effective basic mechanism in pressing is plastic deformation. Because of this, deformation temperature has to be determined by taking this point into consideration. The advantages of warm /hot sheet metal forming method are as follows.

1. Metals can be formed which can not be formed at room temperature.
2. Manufacturing of light and high strength products becomes possible.
3. Press forces decrease.
4. The probability of defect formations on product surface decreases.

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Conventionally the flow forming process is used to form hollow metal blanks over a rotating mandrel and the material is allowed to flow axially along a rotating mandrel. The process is generally used to produce cylindrical components. In forward flow forming process the material flows in the same direction as that of roller but in backward flow forming the metal flows in opposite direction. The forward method is normally preferred because in the backward method, worked material is required to flow over the length of the mandrel, making the material more susceptible to distortion like bell-mouthing at the free end of the blank and loss of straightness. Moreover, backward flow forming is normally prone to non-uniform dimension across the length of the product.

Deep drawing at elevated temperatures has not yet become an industrial application and for this reason it has some indefiniteness's. Literature scope about forming at elevated temperatures is limited and not enough at the time. For this reason, determination of the parameters and the computer simulation of the manufacturing process are prior stages that have to be realized for further studies.

Bolt et al. (2001) carried out a study on the feasibility of using warm forming at temperatures from 100 to 250 °C in order to improve the makeability of aluminium sheet components. It was found that forming at elevated temperature can yield a significant increase in product height, especially for conical products. The hardness of warm formed products does not differ significantly from products shaped at room temperature.

Erdin et al. (2005) investigated the efficiency of sheet metal forming process at elevated (warm/hot) temperatures. It was understood that the critical temperature that makes the deep drawability maximum differs from material to material. This temperature is a complex function of the material and deep drawing process parameters.

The applicability of deep drawing and stretch forming processes is limited by necking and wrinkling, which are related to the material properties. It was investigated by Gavas and Izciler (2007) that more material was drawn into the die cavity without tearing or shape distortions, by increasing the blank holder gap (BHG) in the case of deep drawing of square cups. But tearing also resulted due to excessive wrinkling and buckling at the straight edges if too large blank holder gap was employed. Lin et al. (2007) determined the drawing limit under constant and variable blank holder force.

Jain et al. (1998) investigated experimentally and numerically the limiting draw ratios (LDRs) and other axisymmetric deep drawing characteristics of AA5754-O and AA6111-T4 automotive aluminum sheet materials as a function of die profile radii. It was observed that a decrease in LDR and flange draw-in was a function of the die profile radius. Warm deep drawing process of AA5754-O aluminum alloy was investigated by Palumbo and Tricarico (2007). Grease lubricant was used and the parameters such as the temperature level at the blank centre and the forming speeds were taken into account. It was observed that the blank centre temperature had a strong influence on the process feasibility and thus on the material formability.

Wu et al. (2006) studied a super plastic 5083 Al alloy under biaxial defomation by deforming the sheet into a rectangular die cavity with and without lubrication. Results indicate that reducing the interfacial friction by use of a lubricant altered the metal flow after the deformed sheet had made contact with the die surface. Besides, they observed that changes of the metal flow during forming not only developed a better thickness distribution of the formed part, but also improved cavitations distribution (Kelly and Cotterell, 2002).

The ability to form the material in hot flow forming depends upon the temperature of forming. So in the present investigations the optimum temperature of EDD steel sheets at which it can be flow formed safely into a die will be calculated by observing the thickness distribution along the drawn component. The limiting draw ratio will also be calculated at that optimum temperature.

3. DEVELOPMENT OF INDIGENOUS SETUP

Over the past decade, several researchers have conducted experimental and theoretical analysis in flow forming of tubes to evaluate power and load requirements as well as the effects of process variables such as feed rate, approach angle and percentage reduction on surface finish and forming load. In addition, finite element simulation has been performed by Xu et al. (2001) and Xue et al. (1997) to analyse the material displacement and accuracy in diameter, respectively. As the rapidly emerging trend nowadays is geared towards near net-shape and net-shape manufacturing, flow forming appears to be an attractive alternative to press formed parts especially with its lower forming load requiring considerable smaller equipment and more flexible tooling as compared to conventional presses. However, despite the flexibility and many advantages of flow forming process, investigation of the possibility of the flow forming of solid cylindrical component has not been documented. In this work, a preliminary investigation into flow forming of a simple solid cylindrical components with uniform diameter were conducted in order to gain an understanding as well as assessing the feasibility of this process when forming solid cylindrical components. These include establishing test facilities for conducting experiments.

Die, blank holder and punch in a typical deep drawing operation are designed in such a way that excessive stress concentration does not appear in any part of the drawn cup. So, 4to5 times '*t*' (where '*t*' is the sheet thickness) curvature is given over the punch corner and around 8 to10 times '*t*' curvature is given over the die. Around 2% of the Y.S. pressure is applied on the blank holder to avoid wrinkling of sheet as compressive hoop stresses develop in the flange region of the cup. Also if the blank holding pressure is more, there will be fracture in the sheet just in the beginning of drawing. In conventional deep drawing, the clearance between the punch and die is around 1.2*t*, to accommodate the thickening of the cup wall. In the present research the clearance is decreased and kept below the sheet thickness so that there is excessive plastic deformation of the material over the cup *i.e.*, flow of material along the axis all along the periphery of work (technically called flow forming). Three different dies are used to study the effect of "extent of deformation" over the characteristics of the drawn component. Initially 40% reduction was provided to the thickness (clearance between punch and die is 1.2mm). It was then increased to 25% reduction (clearance 1.5 mm) and finally 10% reduction (clearance 1.8 mm) over 2 mm sheet thickness. The dimensions along with design of these dies are shown in figs 2-3.

Every material has its own coefficient of thermal expansion due to which it expands upon increasing the temperature. Since in the present investigation extent of deformation of 2 mm EDD carbon steel sheet is to be studied at elevated temperature, the material for the dies should be such that it does not excessively change its dimensions otherwise the design of dies will change. Also tooling material should be able to retain its strength at elevated temperatures as there will be heavy friction between tool and the deformable material. So, for this purpose Inconel-600 material was chosen to make dies. The drawn cups are shown in figs 4-5.

An induction furnace [fig 6] was developed to heat the blank. As in a simple transformer when the primary is connected to A.C. Mains an alternating magnetic field is produced in the core and voltage induced in the secondary winding is proportional to primary voltage and frequency. The energy transfer can also take place without the iron core. In this configuration the secondary windings are replaced by a work piece to be heated, the latter can be regarded as a secondary winding with one short circuit turn. This at the same time is the basic arrangement at an induction heating installation, inductor becomes the primary and the work piece secondary, induction eddy currents are induced in the work piece and it gets heated.

An induction heating system consists of a source of alternating current (*AC*), an induction coil, and the work piece to be heated. The basic phenomena which underline induction heating are best understood with reference to the interaction between the coil and the work piece; the role of the power supply in this case is taken into account only in terms of the frequency and magnitude of the *AC* current which it supplies to the coil. By this means, the electrical and thermal effects which are induced in the work piece through its coupling with coil are deduced.

Induction heating relies on two mechanisms of energy dissipation for the purpose of heating. These are energy losses due to Joule heating and energy losses associated with magnetic hysteresis. The first of these is the sole mechanism of heat generation in nonmagnetic materials (e.g., aluminum, copper, austenitic stainless steels and carbon steels above the Curie, or magnetic transformation, temperature) and the primary mechanism in ferromagnetic materials (e.g., carbon steels below the Curie temperature). A second less important means of heat generation by induction for the latter class of materials is hysteresis losses.

The developed induction heating system consists of a power source and tank circuit. The power source converts the power supply from S.E.B to medium frequency single phase output which is fed to a tank circuit. The tank circuit consists of a capacitor and work coil whose resonant frequency is tracked and determines the output frequency of the power sources so the maximum energy is transferred to the work pieces.

This system is designed to heat Iron maximum up to 700°C (slightly above the Curie point).

Along with heating the blank, the lower die was also heated by providing another induction coil around it [Fig. 7]. It is done so that when the hot blank is kept over the dies, it should not develop a thermal shock. This die is heated to a predetermined temperature so that drawing process can be done at a particular temperature.

Since the drawing operation is taking place between dies and the object is not visible during the operation, so temperature measurement system should be such that it does not make contact over either dies or over the blank. So, infrared pyrometers [Fig. 8] are used to measure the temperature at different stages.

The non-contact temperature measurement(pyrometry) is an optical measurement based on the property of all materials to send out electromagnetic radiation (infrared radiation). The infrared thermometer (pyrometer) uses this radiation to determine the temperature. The pyrometer aims with the optics at a certain spot of the object and determines the temperature of this spot. Today typically spectral responses of pyrometers are in the near, middle and distant infrared.

The dimensions of the measured object determine the required spot size of the pyrometer. At least the spot size has to be as big as the measured object to achieve a correct temperature measurement. The spot sizes are dependent on the type of pyrometer and measuring device, they can be calculated using the distance ratio or field of view (FOV). Where FOV is measuring distance/spot size (e.g. 240 :1 means: in a distance of 1200 mm the spot size is 5 mm). Fig. 9 shows the view of the entire experimental test rig along with induction heaters and data acquisition system used in the present research.

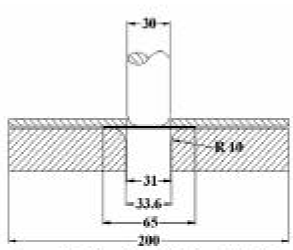

Figure 2: Tooling for 40% Reduction in the Thickness of 2 mm Sheet

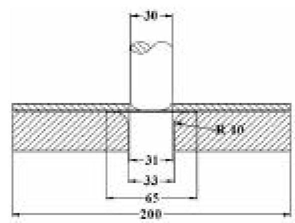

Figure 3: Tolling for 25% Reduction in the Thickness of Thickness of 2 mm Shee

Figure 4: Cups Drawn at 40% Reduction in the Thickness of 2 mm Sheet

Figure 5: Cups Drawn at 25% Reduction in the Thickness of Thickness of 2 mm Sheet

Figure 6: Induction Furnace Used for Heating the Blank

Figure 7: Induction Coil Connected to the Inconel die for Heating it up to 500°C

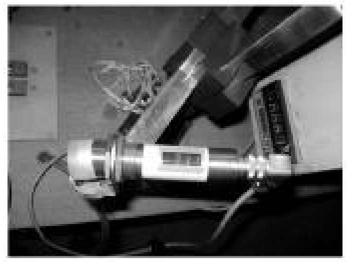

Figure 8: Infrared Pyrometer (A non Contact Temperature Measurement Device in the Range of 0-1000°C

Figure 9: Complete Test Rig

4. METHODOLOGY OF EXPERIMENTATION

The test specimens of different diameters of 2 mm thick EDD (extra deep drawn) steel sheet were prepared upon a lathe. These blanks were heated to a required temperature of 2000C, 4000C and 6000C by using induction heater. Inconel die is also heated simultaneously. Since there will be an increase in the coefficient of friction by increasing the temperature, which may rupture the blank in the initial stages of drawing, a high temperature lubricant 'Molycote' is applied on the interface between die and deformable blank and blank and blank holder. This lubricant is specially becomes effective at elevated temperatures. Tests were performed at 3 different clearances between punch and die.

The load displacement graphs from data acquisition system by drawing different size of blanks are shown in Figs 10 to Fig 16.

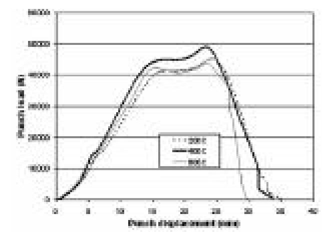

Figure 10: Punch Load Vs Displacement Graph from the Data Acquisition System at Different Blank Temperature of 60 mm Diameter Blank with 25% Reduction in Thickness

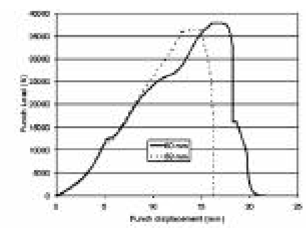

Figure 11: Punch Load Vs Displacement Graph from the Data Acquisition System at different Blank Diameters with 40% Reduction in Thickness and at 600°C Blank Temperature

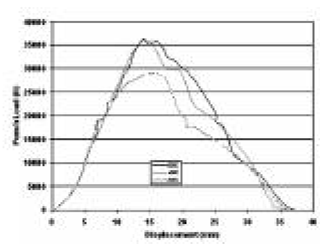

Figure 12: Punch Load Vs Displacement Graph from the Data Acquisition System at Different Blank Temperature of 60 mm Blank Diameters and 10% Reduction in Thickness

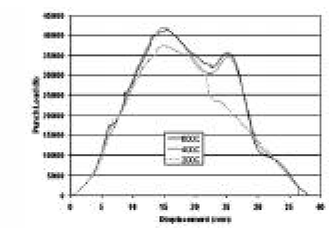

Figure 13: Punch Load Vs Displacement Graph from the Data Acquisition System at different Blank Temperatures with 62 mm Blank Diameters and 10% Reduction in Thickness

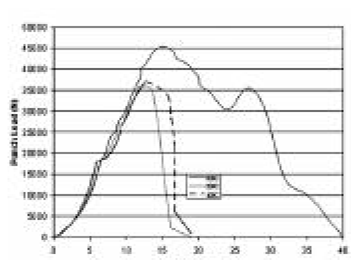

Figure 14: Punch Load Vs Displacement Graph from the Data Acquisition System at Different Blank Temperature of 65 mm Blank Diameters and 10% Reduction in Thickness

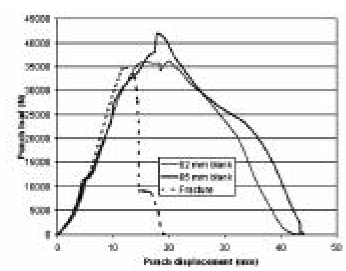

Figure 15: Punch Load Vs Displacement Graph from the Data Acquisition System at different Blank Diameters 25 Reduction in Thickness and 400°C Blank Temperature

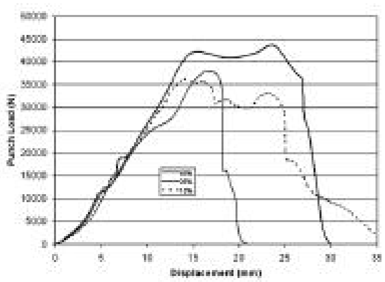

Figure 10: Punch Load Vs Displacement Graph from the Data Acquisition System at Different % age Reduction in Sheet Thickness at 600°C Blank Temperature and 60 mm Blank Diameter

5. RESULTS AND DISCUSSIONS

Warm forming process of EDD Low carbon steel sheet in deep drawing setup is a very promising technique for getting defect free components required for various industrial applications. The present work involving the selection of heating system, pressure application, temperature measurement technique, data acquisition system for recording load displacement gave confidence and proved very successful.

The total setup was designed and manufactured with minimum cost and this approach can be made use of for designing any large scale warm flow forming equipment specific to any industrial application.

The selection of die and punch materials is very important as perfect clearances need to be maintained under repetitive operations. Inconel 600 material is best material as the trials showed good results.

The preliminary trials conducted as shown in figures 4 and 5 revealed that, the cups drawn at 25% reduction at 2000C were free from surface irregularities. Also the limiting draw ratio is acceptable for EDD steel.

The plots for punch load versus displacement shown in figures 10 to 16 revealed that the optimum temperature is 4000C and the reduction of 25% is obtained for a blank diameter of 60 mm. This also gave wrinkle free, crack free and smooth contour for EDD low carbon steel sheets.

6. CONCLUSIONS

The deep drawing process with excessive plastic deformation over wall thickness using warm flow forming concept is a very attractive process for sheet metals. Main advantages of this process are number of stages can be decreased in drawing deep cylindrical components without defects, very poorly formable materials can also be drawn etc, which result in better product quality and higher productivity. This process is being used in industries to produce different types of components like air filters, beverage cans, missile cone, cone for fighter aircrafts, shock absorber covers etc. It can be extended to numerous other products and materials. It has a tremendous future. It provides challenge to researchers to improve the process and equipment for specific industrial applications.

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