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Analysis of Water Hammer Forming on the Sheet Metal

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Abstract

The most important item in the analysis of a metal forming processes is the determination of the magnitude of the applied energy, since it is a parameter necessary for the design of processing equipment. Another important factor is to know the extent of deformation to which a work piece can be subjected before it fails. So, we ought to know the relationship between the energy and the deformation that it produces. The present paper considers relationship between the energy applied and extent of deformation as well as the variations of the radial strains, hoop strains along the radius under different hydraulic mediums is studied.

Keywords: Water Hammer, Metal Forming, Plastic Deformation, sheet metals

1. Introduction

It can be defined as the process in which the desired shape and size are obtained through plastic deformation of the material. This is a very economical process as the desired shape, size and finish can be obtained without significant loss of material and also improves the strength of the product through strain hardening. Both computational and experimental results are analyzed on the phenomena of condensation induced water hammer in steam systems. This work clearly illustrates the potential damage that could occur within a steam system, should a slug of liquid water be allowed to accumulate in the main. Water hammer can be eliminated by a commercial water hammer eliminator, or by a cheap, homemade variety. Eliminators work by using some elastic substance to relieve the instantaneous shock caused by the sudden stoppage of water under pressure. An eliminator as close to each faucet as possible or valve is needed if system does not have a low pressure system. During the 20th century there was considerable research conducted into water hammer with column separation. Bergant et al, report attempts to span all of the significant research that has been carried out and the occurrence of low pressures and associated column separation during water hammer events has been a concern for much of the 20th century in the design of pipe systems for distribution and cooling. The closure of a valve or shutdown of a pump may cause pressures so low that the liquid will cavitate. The collapse of vapor cavities and rejoinder of water columns can generate nearly instantaneously extremely large pressure that may cause significant damage or ultimately failure of the pipe system. Water hammer forming of 50.8-mrn-dia low-carbon-steel sheet specimens using a water column as the energy transmitting medium, presented that allows an estimation of the pressure variation, within the water column, with time to be made. The energy is supplied from a falling weight that impacts a punch resting on the top surface of the water column. The large mass of the falling weight relative to the mass of the water column allows an energy balance to be made between the kinetic energy of the weight and the strain energy absorbed by the column. Experimental results are presented that show the theory to be capable of providing a reasonable estimation of pressure variation. In spite of the complexity of the situation and the assumptions that have been made, the analysis of water hammer free forming of small diameter sheets, assuming a simple spring mass system with a high mass ratio, does allow an estimate of the pressure time profile to be made and an estimate of the polar deflection of the sheet .

The use of a water hammer process for sheet metal forming has been described in the past and its usefulness as a manufacturing process demonstrated. Attempts have been made to analyze the pressure generated in water columns when impacted by falling masses by using one-dimensional elastic-wave-propagation theory (Donaldson, 1964). This type of approach allows the prediction of the pressure time profile (including transient effects) but only with a rigid end to the water column. When a flexible end, such as sheet metal, is used, the wave propagation method is more difficult to apply since the wave- reflection conditions at the flexible end are, to some extent, unknown. Osakada stated that the deformed shape of the material is also affected by the strain rate effect. In general, deformation is dispersed when the strain rate effect is significant. This effect is most utilized in super plastic forming in which occurrence of necking is avoided and a very large deformation is attained. Since this phenomenon is usually caused at a very low strain rate, it is desirable to develop metals which exhibit significant strain rate effects at high strain rate. As an example, a super plastic aluminum alloy which causes a significant strain rate effect at a high strain rate is introduced.

2. Experimentation

The working temperature is lower than the recrystallization temperature of the material and then the process is called cold forming. According to the speed of (Energy Rate) forming, the processes can be divided into the following categories. Explosive forming, Magnetic pulse forming and Electro Hydraulic forming come under (High Energy Rate) High Speed Forming processes. This present work comes under high speed forming. The speed of deformation in water hammer forming is less than that in explosive and Electro hydraulic forming but greater than that of conventional forming processes and the Experimental setup of the water hammer forming is shown in Figure 1.

Figure 1: Experimental setup of the water hammer forming

2.1 Water hammer forming theory

Water hammer forming process is similar to Explosive forming process in producing the shapes like conical, convex and cup shaped. This is somewhat slower than the explosive forming process, similar to explosive forming in which an enormous amount of energy is applied to the work piece, which deforms into required shape within fraction of the second. In this process large amount of kinetic energy of a falling weight is converted into pressure energy with the help of water hammer forming equipment. The pressure energy is directed to the blank, which will deform the blank into the die shape. The central deflection of blank depends on the amount of pressure developed in the cylinder, which indirectly depends on the height of fall and weight of the fall. Also the thickness and size of the blank affects the central deflection and energy required i.e. height and weight. The water hammer effect is explained below in the case of sudden closure of cylinder, in which fluid in motion can be taken as the basis for analyzing the pressures developed in the cylinder of the water hammer forming equipment. There is a sudden repeated knocking in the pipeline when the pressure is released suddenly from the tap in a toilet. This mini version is known as “water hammer”. Its magnified level is dangerous for irrigation and hydroelectric projects, but it has great application in sheet forming process. The pressure waves that are created in the column of water by impact of plunger; These created pressure waves are transmitted and exert the force on work piece, which is plastically deformed by straining in an arrangement of die.

The efficiency of the Water Hammer Forming, which is highest order compared to other High Velocity Forming processes, is defined as the ratio of the energy absorbed in plastic deformation of the work piece to the kinetic energy of the drop weight at impact with the plunger. Efficiency is typically between 40 and 50 percent. A plunger is used to produce shock waves in a fluid medium and the shock energy is used to deform the work piece into required shape. In WHF process, a suitable metal blank is placed over a vented die and a pressure cylinder filled with water. The cylinder is designed to withstand about 200 atmospheres is located on top of the blank with a rubber O-ring in between. The cylinder top flange is bolted to the die holder and a plunger is positioned in the pressure cylinder in contact with water. A drop weight is taken to the required height and allowed to fall under gravity on to the plunger, which initiates a shock wave in the water medium. The energy associated with the pressure shock wave is utilized to transform the work piece into the shape of the die. Thus in water hammer forming process kinetic energy of falling weight is converted into pressure energy in the water column which pushes the blank to the shape of the die. Three fluid mediums are considered for these studies are Water, Vegetable oil and Grease. To make the system leak proof we have used rubber 'O' rings of different sizes and different thickness at different places. One 'O' ring of 4 mm thick and 36 mm diameter for the plunger and two 'O' rings of dia 100 mm and 120 mm of thickness 5 mm were used at the bottom of the cylinder. These 'O' rings were applied with grease to act as leak proof and pressure tight. Water hammer forming of annealed aluminum and copper blanks of diameter 120 mm and thickness of 0.8 mm, has been taken for experimental work and the influence of the process parameters like, pressure transmitting medium, potential energy, distribution of hoop strains, radial strains, and central deflection of the deformed metal has been observed. Pure aluminum and copper sheets of 0.8mm thickness and suitable circular blanks of 120mm size are cut with shears and the edges of the blanks are filed to the correct shape. For all the blanks center is located then the blanks are marked with concentric circles with a radial interval of 10 mm and two radial lines with an included angle of 45 degrees. The marked aluminum and copper blanks are annealed and used for deformation in water hammer forming process. The pressure cylinder is filled with water or any chosen hydraulic fluid and the plunger is pushed through the guide bush to position on the water column. The weight or ram is lifted to the required height and suddenly relieved. The shock waves produced in fluid column develop high pressures with this impact load on the plunger. The high-pressure fluid column deforms the blank into the die and produces the required shape. The above procedure is repeated.

2.2. Variation of central deflection with energy

For finding the variation of central deflection with energy, numbers of specimens (with diameter 120mm and 0.8mm thickness) were tested with only one blow given to each specimen. The deformed blank has a convex cup at the center and the flange portion is flat. For measuring the central deflection the following procedure is adopted. A steel rule is placed on work-piece, so that its edge passes through the center of the cup. Care should be taken to keep the steel rule exactly at 90 to the cup flange. Then with help of a Vermeer calipers (or depth micrometer) the central deflection of the cup is measured.

2.3. Variation of radial and hoop strain with centre distance

For finding variation of radial strains and hoop strains with distance from the center of the cup, two radial lines are marked on the blanks with included angle of 45 degrees and concentric circles are drawn at 10-mm intervals. For radial strains the readings were taken at radial segments *Vs* mean center distance of that segment. For hoop strains the variation of Circular segment between two radial lines at each radius were noted. Only one specimen from each type was tested at certain energy level. The measurement of the above strains is described in the next section.

2.4. Procedure for evaluation of radial strains

The Initial length of any radial segment on the blank along the radial line is measured and it is equal to R. Thin wire is stretched, after the formation of cup, along the deformed segment to measure the final length of the radial segment that is curved. Let this length be R1. The change in length of the segment is given by (R1 -R) and respective radial strain is given by

$$(R1-R)/R$$

This strain corresponds to the third point of the chosen segment. Likewise radial strains for other segments also can be found.

2.5. Procedure for evaluation of hoop strains

The Initial length of circular segment at radial distance can be found by the following equation.

$$L1 = 2\pi rl \times \theta/360$$

Here $\theta = 45$ degrees.

$$L1 = 2\pi rl \times 45/360 = \pi r/4$$

The Final length of each segment after deformation is evaluated with a thin wire stretched along the deformed segment and measuring the length of the wire with Vernier calipers. Let this be equal to L2. Then the corresponding hoop strain experienced by the segment is (L2 – L1)/L1. Likewise the hoop strains for other segments can be found.

Maximum deflection takes place at 75cm ram height with water as the medium, but maximum deflections are obtained with oil as the medium on Aluminum material is shown in Figure 2. Maximum deflections are obtained on copper material with water as the medium is shown in Figure 3.

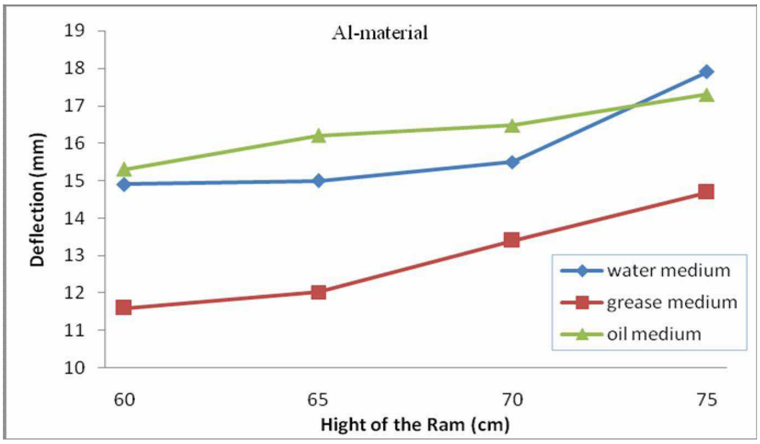

Figure 2: Deflection of Aluminum material with different mediums

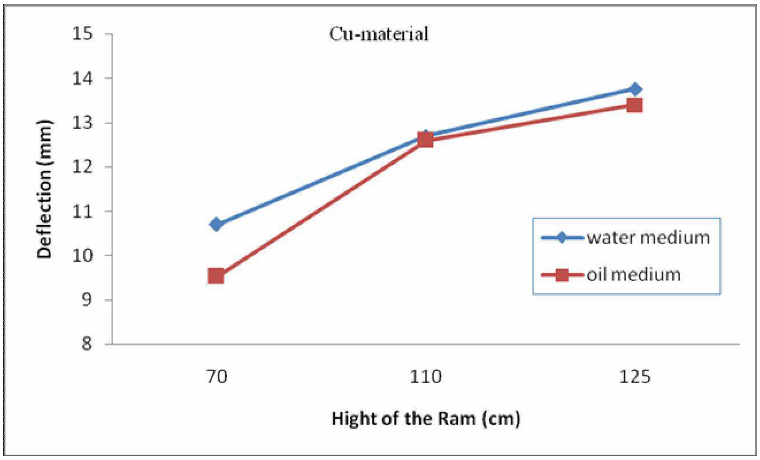

Figure 3: Deflection of Copper material with different mediums

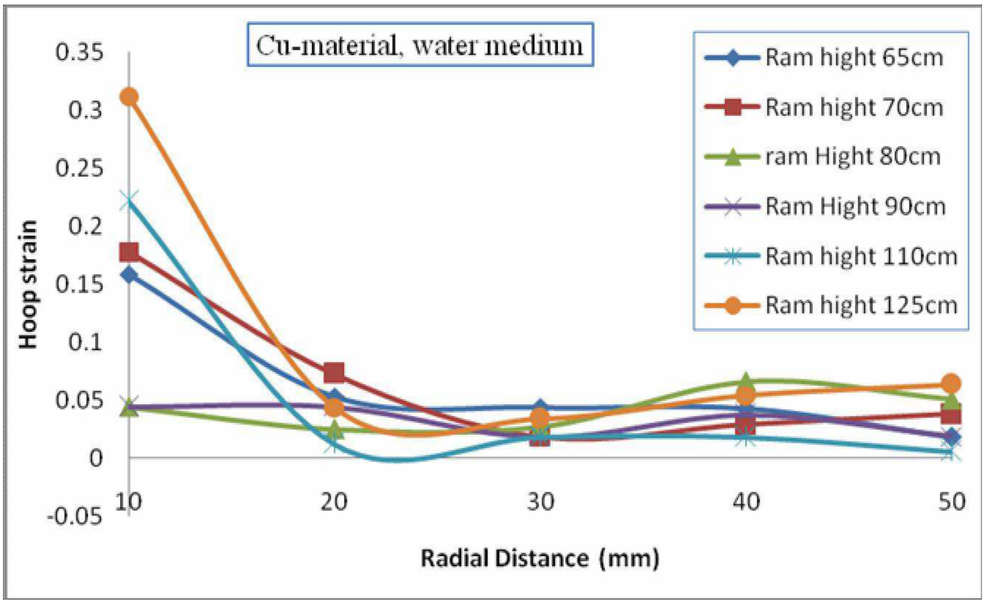

Figure 4: Hoop strain Vs Radial distance for copper material at different ram heights

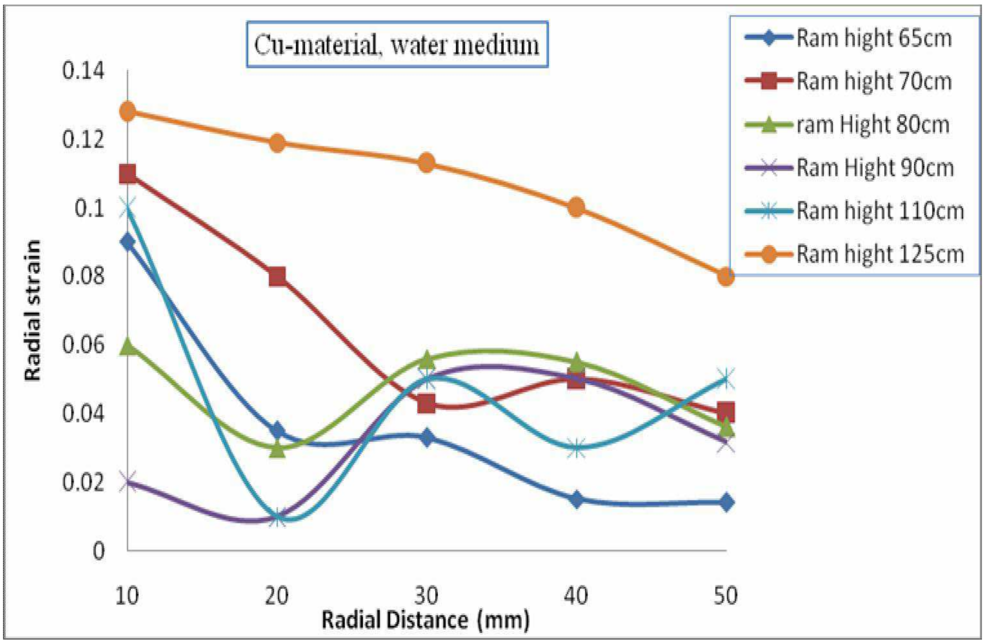

Figure 5: Radial strain Vs Radial distance for copper material at different ram heights

Hoop strains and radial strains variation along with radial distances for different materials and different ram heights are shown in Figures 4-5. Maximum strains are obtained at radial distance of 10mm for both Al and Cu materials.

4. Conclusion

From the experimental data and graphs for radial strains it is observed that the radial strains and hoop strains are almost negligible in the flange region of cup compared to the region near to the center. This shows stretch forming of the material in the center of the cup. This is understandable, since in the present experimental setup the cylinder is directly seated on the blank and the swing bolt force is restraining the movement of the blank in the flange area. To avoid this it is suggested that a step should be machined in the die holder. The cylinder should rest directly only on the step machined on the die holder and the sheet metal gets effective sealing and contact only through the rubber "O"rings arranged at the bottom of the pressure cylinder. In case of the data obtained for the deflection of the metal piece it was observed that as the potential energy is increased there is an increase in deflection of the metal. With accessories like motor driven positing device for drop weight, we can adopt water hammer forming process very efficiently for low volume production in small industries. Suitable dies can also be designed to achieve deep drawing with multiple blows and impact bulging for tubes etc.

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