Forging of Naval Brass (ASTM B16) - Finite Element Analysis using Ls Dyna

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Abstract. Forging is one of the important manufacturing process in which products like connecting rod, transmission shaft, clutch hubs and gears are produced. Finite element analysis (FEA) in forming techniques is of recent interest for the optimal design and determination of right manufacturing forming process. The data from the numerical results can help in providing the information for selecting the ideal process conditions. Thus aside from experimental values, simulation by the finite element analysis software’s such as LS DYNA can be used for the analysis of strain distribution in forging processes. In the present work, Finite element simulation of open die forging of naval brass (ASTM B16) is done at an optimal temperature. An advanced multi physics simulation software package by the Livermore software technology cooperation LSTC - LS DYNA is utilized for the simulation of forging process. For the forging validation, experiment is conducted with a cylindrical billet having height 45 mm and diameter of 40mm. The numerical results are compared with that of experimental results carried out at the same temperature and dimensions for validation. The distribution of strain is analyzed. Energy analysis due to impact load is detailed. The simulation results are found to be in good agreement with the experimental results.

1. Introduction
Naval brass (ASTM B16) is a copper alloy of about 39% of copper, 10% of zinc and 1% of tin with a trace of lead. It comes under the division of brass called the Duplex brass. This type of brass is harder than the others. Naval brass primarily has its application in marine services. The Tin in the alloy of copper improves the corrosion characteristics of the naval brass (ASTM B16). The machinability of the naval brass is increased with the presence of lead. The ASTM B16 has machinability of about 35% free machining brass. The Tin present also prevents the dezincification. Thus it is used in areas where “condenseritis” has to be prevented. Condenseritis is a problem pertaining to dezincification in brass tube in ships. The material has got higher tensile strength and resistance to wear and hence it is used in many industries for manufacturing of bushing and wear strip and also as fasteners and valve stem. The naval brass can be processed in numerous methods such as blanking, drawing, pressing and forging. Forging gives improved properties in terms of strength and fidelity of the product.

A few literature works are reported on forging process. The forging simulation process was done in LS - DYNA on wrought magnesium alloy and microstructure analysis was made [1]. Parameters such as temperature, strain rate and friction can affect the forging process [2]. The forging process above the recrystallization temperature produces high ductility, since re-crystallization keeps the material from strain hardening, which in turn enhances the yield strength and hardness [3]. In order to optimize and reduce costly trial iterations in the forming process an insight into the deformation mechanics could prove to be very useful [4]. A study was made to understand the plastic deformation properties of 42CrMo in the upsetting process. The study simulated the stresses, strains, changes in temperatures at different regions of the billet and also analyzed the forging defects in the process. The temperature and the stress results obtained is in concord with the forging practice and theories [5]. A model for predicting the heat transfer...
process was proposed by [6]. The heat transferred during the process also depended upon film thickness and roughness. The presence of dynamic recrystallisation had a significant role in grain refinement and material softening during forging which helped to improve workability and mechanical properties [7]. Dynamic recrystallisation is more when the temperature of the work piece is less and the strain rate is more. The effect of strain distribution on micro structural developments during forging in a newly developed nickel base super alloy was analyzed [9].

The above literature shows that numerous factors such as the temperature, density, strain rate, shape formed and the friction influence the forging process and the properties of the material forged also vary with the above parameters. In the present work numerical simulation of forging is done and the analysis of the strain distribution in the billet at the micro structural level is made. Though there are numerous advantages of manufacturing ASTM B 16 using forging, only few works are reported in literature on this specific material. The present work is focused on understanding the forging behavior of ASTM B16 in an open die process using LS-Dyna software. The results are validated with experiments of same dimensions. The strain distribution and other factors including various forms of energy are analyzed at the temperature at which forging is carried out.

2. Methodology:

2.1 Experimental set up:
In the present experiment, the dimension of the cylindrical billet is 45mm in height and diameter 40 mm. Experiments of open die forging were carried out at Shanmugha precision forgings in a 100 ton hydraulic press forging machine. A photograph of the machine used is shown in Figure 1. ASTM B 16 is heated to 600°C in an oil fired furnace. An IR sensor (Metravi, Infrared Thermometer) of non-contact type is used in measuring the temperature of the billet. The billet is kept in between upper and lower die made of die steel (H13 material). Forging is carried out and the entire process of forging is recorded using a Basler A602f high speed camera which is capable of recording 1500 fps for a 32 x 32 resolution. The video graphs were later analyzed frame by frame using stream pix software. The dimension of the billet (height and diameter) is carefully measured using a vernier caliper before and after the processes.

Figure 1. Experimental setup
2.2. LS DYNA modeling:

The forging of ASTM B 16 is simulated using a commercial code LS-Dyna which is a Finite element based code for modeling the forging process. LS DYNA Version 5.6 is used for 3D modeling the forging process of the component. The model consists of an upper and a lower die of dimensions having height of 50 mm and diameter 80mm. The dimension of the cylindrical billet having height of 45mm and the diameter 40 mm which is same as that of the experiments is kept in between the dies. The upper and the lower die are modeled as (MAT_RIGID) which indicates that the materials don’t undergo any deformation. The billet is modeled as a material which undergoes piecewise linear plastic material indicating that the material undergoes linear deformation. The properties of the upper, lower die and the billet are shown in Table 1. The initial temperature of the billet is given. In the present case in both experiments and numerical simulation the Die is not preheated. Dies and billet is designed by shape mesher under the element and mesh. The billet is given mesh size of 50 number of elements along the height and 20 number of elements along the circumference. The lower billet is constrained in all the three directions. The upper billet is constrained in x and z direction. The upper billet is given a velocity of 254 m/s in the +y direction. The initial temperature assigned to the billet is 600°C which is same as that of the experiments.

| Properties         | Upper and lower die | billet     |
|--------------------|---------------------|------------|
| Density            | 11265 kg/m³         | 8497 kg/m³ |
| Young’s modulus    | 9.6×10¹¹ pa         | 9.6×10¹⁰ pa|
| Poisson ratio      | 0.3                 | 0.3        |

3. Results and discussion:

In this paper the forging process of the naval brass is simulated and various categories of energy change in the process is analyzed. The experiment and the numerical simulation are carried out and the end products are compared for validation as in Figure 2 and Figure 3 respectively. The end product of the numerical simulation is similar to the final forged component. Through high speed video analysis the material deformation in every fraction of time is compared with the numerical simulation. Also the dimensions of the billet before and after forging are compared and they are found to be the same which validates the present work. The simulated product shows that the numerical process that is carried out is in accordance with the real time forging process. The result observed during the forging process during simulation is stated below. The final product in the experimental and the simulation setup is shown in Figure 4 and Figure 5.
The analysis of the strain distribution is studied from the forged product and is shown in Figure 6. It is observed that the strain rate is lower at the regions which have got smaller grain sizes. Similarly the occurrence of larger grains results in increased strain rate. This is because dynamic recovery has taken place where the strain rate is less and the dynamic recrystallization has taken place where the strain is more. It is also noted that there are smaller size grains with higher strain rate which undergoes nucleation in the billet and the nucleation rate varies with the strain rate. The region closer to the center has smaller grain size but increased strain rate which is due to more possibility of nucleation and have quicker dynamic recrystallization than larger sized grains. This leads to inhomogeneous microstructure of the billet.
The total energy experienced by the billet comprises of potential and kinetic energy. From Figure 7, it is shown that until the upper die hit the billet the total energy is zero and when the upper die hit the billet at $3 \times 10^{-3}$s the total energy of the billet increases steadily because of transfer of kinetic energy from the upper die to the billet. The slight decrease in total energy is because when the die hit the billet there will be fraction of decrease in velocity at that moment, which decreases the kinetic energy thereby slightly decreasing the total energy.

From the figure 8 it is found that there is a significant increase in the kinetic energy along the time. This aspect can be associated to the force which is needed to overcome the friction and very importantly to attain its yield strength.

Figure 9. Shows the internal energy vs. time of the billet. It is observed from the figure that the internal energy increases gradually once the upper die hits the billet. It is due to the hammering effect produced by the die on the billet during the forging process thereby giving external energy to billet making it to vibrate and hence gradually increasing the internal energy. Thermodynamically external work on a body increases its internal energy.
From figure 10 it can be observed that as soon as the upper die hit the billet the resultant force instantaneously increases and then decreases immediately because once the billet reaches the yield point, it requires only small increase in the resultant force for the billet to reach its optimal plastic deformation.

4. CONCLUSION:
The forging behavior of ASTM B16, naval brass is studied experimentally. FEM based 3D modeling of forging is done using LS DYNA package for the same experimental conditions. The deformed size is used to validate the model. The strain distribution of the forged product is analysed in detail. Also the Energy analysis due to impact load is detailed. The simulation results are found to be in good agreement with the experimental results. Thus forging process can be simulated using LS DYNA software package, which in turn can be used to optimize the forging process parameters. The FEA model generated by the LS
DYNA can also be used to study the strain distribution in the forged billet and various other parameters which is important in the forging process.

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