DETERMINATION OF LOAD AND STRAIN-STRESS DISTRIBUTIONS IN HOT CLOSED DIE FORGING USING THE PLASTICINE MODELING TECHNIQUE

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Abstract An axisymmetric hot closed die-forging process has been studied by physical modeling technique using the plasticine. To observe the material flow pattern, layers of plasticine with different colors were used. The normal direction to the layers was considered a principal direction. The strain distribution was obtained by measuring the thickness of the plasticine layers. Based on the strain distribution, the stress distribution and the forging load were computed, respectively. Several ring compression tests were performed using Vaseline, soapsuds, baby powder, facial tissue and plastic wrapping to determine the effect of different lubricants on the plasticine modeling. In order to verify the validity of the modeling data, a similarity study between plasticine and Ck45 was made. Considering the effect of strain path, the load obtained by this technique matched fairly well with the actual load.

Key Words Hot Closed Die-Forging, Physical Modeling, Plexiglas, Plasticine, Strain, Stress, Load

چکیده به منظور تعیین توزیع کرنش ،در فرآیند آهنگری گرم، از روش شبیه سازی فیزیکی استفاده گردید. در این روش قطعات بیلت از روی هم گذاشتن لایه‌های خمیر بازی یکسان ولی با رنگ‌های مختلف تهیه شدند. شرایط اصطکاکی مختلف بین قالب پلکسی‌گلاس و خمیر بازی توسط چندین روانکار نظیر آب و صابون غلیظ،پودر تالک، وازلین، دستمال کاغذی و پلاستیک بررسی گردید. در نهایت مشخص گردید که روانکار آب و صابون غلیظ بخوبی شرایط اصطکاکی بین قالب و خمیر بازی را برای قطعات واقعی آهنگری شبیه سازی می کند. با فرض قرار دادن راستای عمود بر جهت سیلان به عنوان یکی از جهات اصلی، توزیع کرنش در قطعه از روی اندازه گیری ضخامت لایه های تغییر شکل یافته بدست آمد. از روی توزیع کرنش به کمک روابط پلاستیسیته به توزیع تنش در قطعه واقعی از جنس Ck45 که هم اکنون در صنعت در حال تولید است پی برده شد. از روابط موجود بین کرنش‌ها و تنش‌ها در حالت تقارن محوری استفاده گردید تا توزیع نیرو در قالب و در نهایت نیروی شکل دهی بدست آید. نتایج حاصل از نیروی بدست آمده به روش شبیه‌سازی فیزیکی با نیروی بدست آمده از آهنگری واقعی مقایسه گردید. نیروی بدست آمده از مدل سازی با در نظر گرفتن مسیر کرنش نزدیک به نتیجه تجربی بود.

1. INTRODUCTION

Plasticine is a trade name by Harbut, U.K. and is modeling clay for children as a playing material [1]. The main content of plasticnie is fine lime powder with grease as a binder. Plasticine is one of the most widely used modeling materials for studying of plastic deformation of metals [2]. Its characteristic is very similar to deformation of hot steel. The experiment using plasticine is very simple and easy to handle in a laboratory with inexpensive equipment. The flow stress of plasticine is almost 1/500 of that in hot mild steel [3]. For this reason, a low tonnage testing press can be used for modeling studies. Plasticine modeling in Plexiglas dies provides valuable information about the flow patterns that assist to detect internal defects and optimize the billet and preforms in forging and other bulk forming processes. There have been many reports of plasticine modeling in the literature .The results of these modelings have provided researchers varying amounts of plastic flow information. Review of the literature indicates that only qualitative information is obtained by this technique in the bulk deformation processes. The quantitative results have been achieved indirectly by applying the results of the plasticine modeling to the numerical techniques like finite element methods.

Chu et al. [4] studied the process sequence design of a large Axisymmetric hot forging product of AISI 4130 in nozzle type by using the plasticine and lead as the model materials .The result of this study was used in finite element modeling for the stress analysis. Kim et al. [5] used layered plasticine for the study of the flow in hot closed die forging. Misilolek [6] used plasticine to understand the role of the metal flow in deformation history in the extrusion process.

The main objective in the present work is to achieve some quantitative results directly from the physical modeling without applying any numerical methods. In hot closed die forging process using the plasticine, an Axisymmetric product which is manufactured in industry has been modeled by plasticine technique .The load, stress and strain distributions were obtained with some range of approximations without applying any numerical method. To model the real frictional effects, several ring compression tests have been performed on plasticine with different lubricants.

2.PROPERTIES OF PLASTICINE

Plasticine is an easy to deform material and thus it has been used widely as a modeling material to simulate hot deformation of steel. In the present experiments, Harbutt's plasticine was used for the modeling study, being composed 52.3% evaporable material such as grease and 47.7% of ash material in which $CaCO_3$ is a main solid constituent [5]. Plasticine is a strain hardening material with small strain rate dependency at room temperature [1]. The mechanical properties of plasticine are known to vary with age, temperature, and moisture. The flow stress of plasticine can be expressed as [5]:

$$\overline{\sigma} = k\overline{\varepsilon}^{n} \ \dot{\overline{\varepsilon}}^{m} \tag{1}$$

the work-hardening exponent, or n, ranges from 0.2- 0.3, whilst the strain–rate sensitivity, m value, is about 0.05-0.06.

3. THE EXPERIMENTAL WORKS

3.1 Ring Compression Test The friction factor during the hot working of steel normally falls between 0.2-0.4 with graphite base lubricants and 0.7–1.0 when no lubricant is used [7].

The friction at the interface between the die and the work piece depends on the lubricant and the surface roughness. Both of these factors are affected mainly by the pressure and the temperature at the interface. The well known ring compression test is an easy way to measure the friction factor at the interface of die and the work piece [5]. In this work, the plasticine was formed into rings by plexiglass die set. The rings were 30mm inner diameter, 60mm outer diameter and 20mm height. The Rings were kept in the freezer for two hours and left in the air for 24 hours [4] before performing the experiments. The rings were upset by a pair of flat plexiglass dies. A 30 tons universal testing machine was used for all the ring compression tests and other experiments in present work.

To find similar frictional conditions to those in real hot forging process, several lubricants were used in ring tests. Vaseline, baby powder, facial tissue, plastic and soap suds were the lubricants used in these experiments. The ram velocity used in ring tests was 15mm/min. The friction factor was obtained for every lubricant by measuring the ring dimensional changes and reading the calibration curves [7]. Table 1 reveals the results of ring compression tests for different lubricants in plasticine modeling .The soap suds with friction factor of 0.3 shows similar frictional behavior to graphite in the real forging process. Therefore, it

TABLE 1. The results of ring compression tests for different lubricants in plasticine modeling .

Lubricant	Friction Factor
No lubricant	1.0
Baby powder	0.5-0.7
Facial tissue	0.4-0.5
Plastic	0.4
Soap suds	0.3
Vaseline	0.05

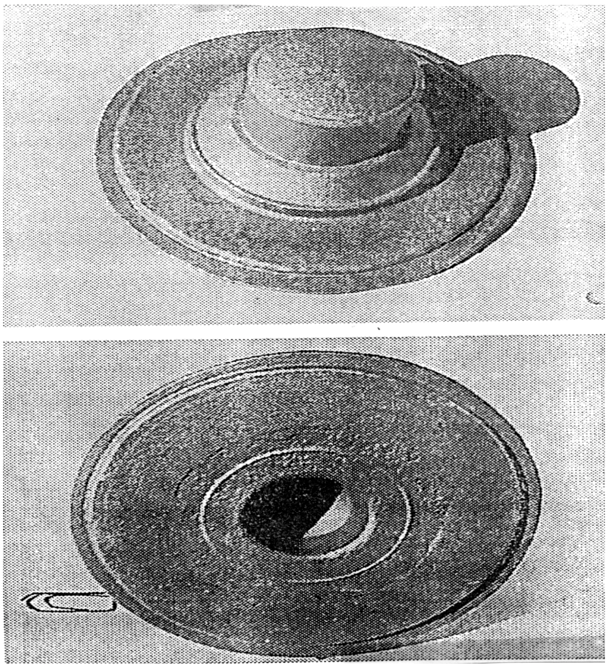

Figure 1. An Axisymmetric hot forging product of Ck45 manufactured in industry by a 500 ton hydraulic press

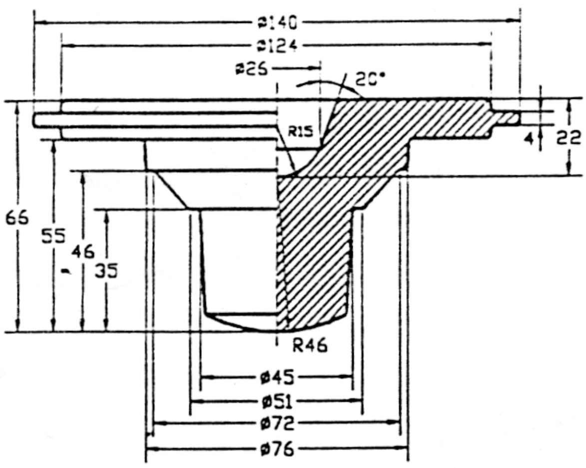

Figure 2. The geometry of the final product of Ck45.

was selected for the modeling experiments in the rest of the tests in this work.

3.2 Physical Modeling Experiments In order to have a reference for checking the physical modeling results, an Axisymmetric hot forging

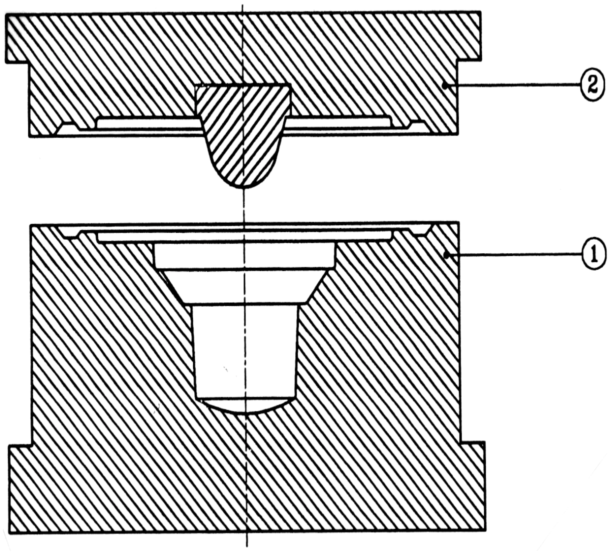

Figure 3. Plexiglas die set for physical modeling experiments.

Figure 4. The billet and deformed plasticine specimen.

product of Ck45 being manufactured in industry was selected. This part is manufactured by a 500-ton hydraulic press and it has been shown in Figure 1.

The initial billet temperature is 1100^{o}C and the initial die temperature is 400^{o}C .The cylindrical billet dimensions are 75mm diameter and 64mm height. The geometry of the final product is given in Figure 2. The actual forging load is 270 ton.

For the studies of physical modeling, the die set was made with plexiglass using the lathe Machine. Figure 3 displays the die set made in this work.

Layered plasticine with different colors were used for making several billets of 64mm height and 75mm diameter. The geometrical scale factor between Ck45 and plasticine used in the experiments was 1 to 1. The temperature during the tests was about 19^{o}C.

The first plasticine sample was forged in one-

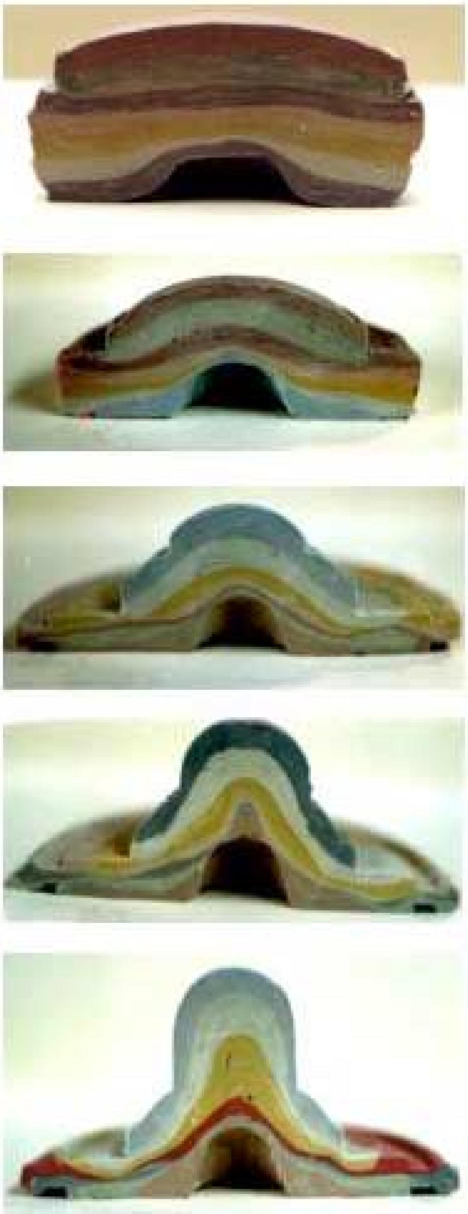

Figure 5. The patterns of material flows at five stages by cross sectioning the deformed specimens.

stage using soapsuds as the lubricant. Figure 4 shows the deformed sample. To see the flow pattern, the specimen was sectioned and displayed in the figure.

To follow the strain path, the second experiment was preformed in five different stages with similar frictional conditions. Totally five specimens were used in different stages. Figure 5

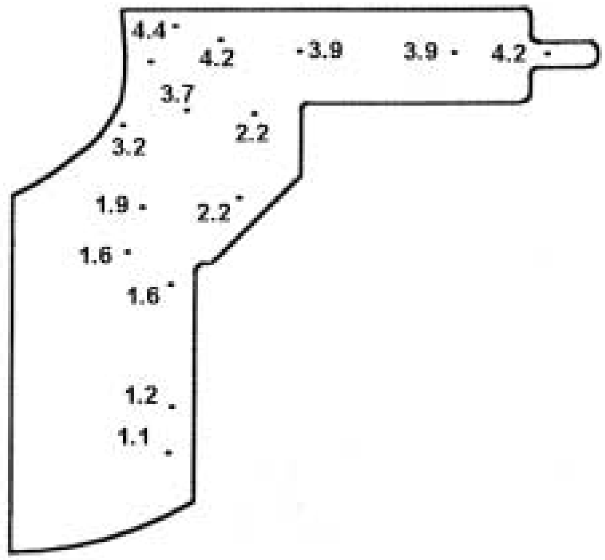

Figure 6. The effective strain distribution in the first sample of the plasticine modeling.

reveals the patterns of material flows at different stages by cross sectioning the deformed specimens.

4. DATA PROCESSING AND DISCUSSION

Knowing the flow directions and thickness variations on plasticine layers , the strain and stress distributions and the forging load were obtained. It was assumed that the principal directions coincided on the normal to the plasticine layers and the flow directions. Accordingly, the Axisymmetric effective strain $\bar{\varepsilon}$ and the radial strain are [8]

$$\bar{\varepsilon} = \varepsilon_1 = \ln(t_2 / t_1) \qquad (2)$$

where t_2 is the final layer thickness and t_1 is the initial layer thickness. Using digital caliper, the thickness variation in Figure 5 was measured at different locations and used in equation 2. Figure 6 displays the computed effective strain distribution on the work piece.

Using these strain values and applying the Ck45 material properties the stress values were found on the real part .The flow stress data for Ck45 is [8]:

$$\bar{\sigma} = K(T)\bar{\varepsilon}^{\,n(T)}\ \dot{\bar{\varepsilon}}^{\,m(\bar{\varepsilon},T)} \qquad (3)$$

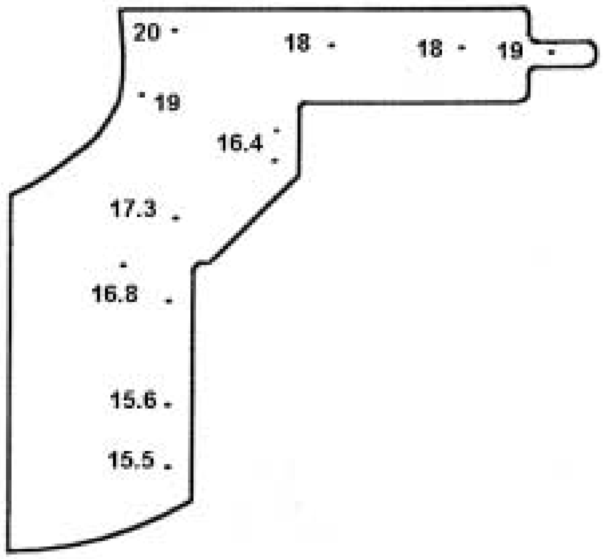

Figure 7. The effective stress distribution in the first sample of the plasticine modeling.

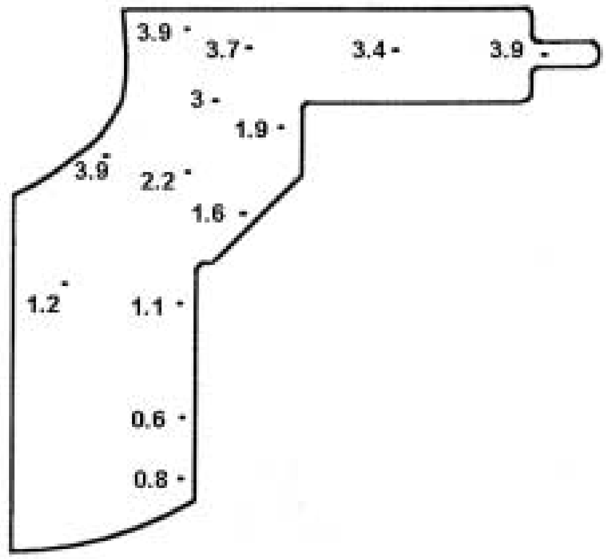

Figure 8. The effective strain distribution in plasticine modeling sample considering the effect of strain path.

Where T is the material temperature in Kelvin and:

$k(T) = 4948.98 - 672.75 \ln T$ (MPa)

$n(T) = 10^{-3} \times (-6.820+0.392T-2.221\times10^{-4}T^2)$

$$m(\bar{\varepsilon}, T) = a(\bar{\varepsilon}) + b(\bar{\varepsilon})T$$

$$a(\bar{\varepsilon}) = -0.04897 + 0.1008\bar{\varepsilon} - 0.2997\bar{\varepsilon}^2 + 0.2575\bar{\varepsilon}^3 - 0.0667\bar{\varepsilon}^4$$

$$b(\bar{\varepsilon}) = 10^{-3} \times (0.1620 - 0.266\bar{\varepsilon} + 0.6548\bar{\varepsilon}^2 - 0.4667\bar{\varepsilon}^3 + 0.1026\bar{\varepsilon}^4)$$

For example according to the above flow stress expression for Ck45 steel, at 1100°C (1373°K), the followings are calculated:

K(T) = 18.5 MPa   n(T) = 0.12   and

$$m(\bar{\varepsilon}, T) = 0.06$$

Assuming the isothermal conditions, the effective stress distribution in the actual work piece was computed. Figure 7 shows the results.

According to Figures 6 and 7 the flash zone has the most effective strain and stress which is quite reasonable .The load required for forging was calculated using the following expression:

$$F = \int \sigma_1 \mathrm{Cos}\alpha\, dA + \int \tau \mathrm{Sin}\alpha\, dA \qquad (4)$$

Where

σ_1 : Normal stress at die neighborhood

τ : Frictional shear stress

α : The angle between normal to die surface and vertical direction

The result of the load calculation with this method was 309 tons. To investigate the strain path effect, thickness measurements were done on all the stages of Figure 5. The final strain distribution was obtained by accumulating the local strains at different stages. Figures 8 and 9 show the effective strain and stress distributions, respectively. The calculated load with this method was 280 tons.

Compared with the actual load, the results of plasticine modeling are very close when the effect of strain path is considered. When the modeling is done without consideration of the strain path, the strains, stresses and forging load become considerably larger.

5. CONCLUSION

It was demonstrated that physical modeling simulation of Ck45 Axisymmetric part was useful

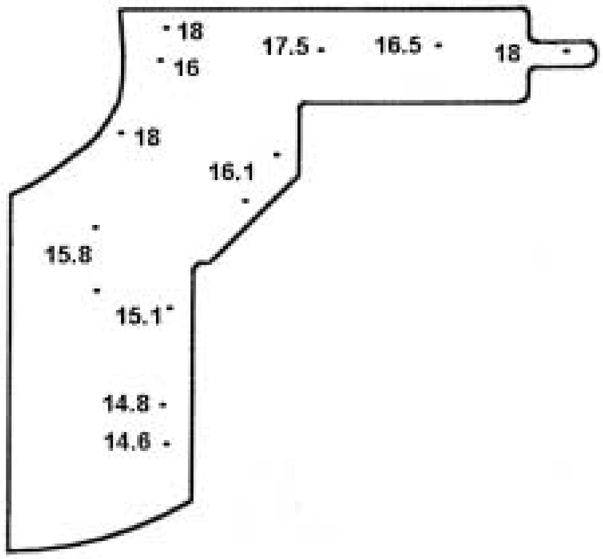

Figure 9. The effective stress distribution in plasticine modeling sample considering the effect of strain path.

in obtaining some useful quantitative results. It was found that application of soap suds between plexiglass and plasticine creates similar frictional effect to graphite in the real forging process. Assuming the normal direction to the layers as a principal direction, the strain distribution was obtained by measuring the thickness of the plasticine deformed layers. The stress distribution and forging load were obtained by applying the resulted strains in CK45 flow stress expression. To improve the results, thickness measurements were done at five stages of deformation and the total strains were calculated by accumulating the strain increments. The forging load obtained by this method showed less than five percent difference with real forging load.

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