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A Review of Cold Forging

Engineering

KEYWORDS : Cold forging; pressing; squeezing; metal work; hammering; ambient temperature; tip test; T-shape compression test.

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ABSTRACT

Cold forging is a process in which the shape of metal is changed, by mechanical forces only, using the ductile properties of metal such as pressing, squeezing, or hammering forces. In forging, a metal work piece is plastically deformed, at ambient temperatures. The modular system to control material flow during cold forging processes by additional hydraulic axes using different process variables as well as the appropriate process and equipment technology is presented in this contribution. It has been shown that due to the controlled movements of the tool components both the robustness of the forming processes and tool loads in conventional cold forging process are controllable leading to enhancement of forming limits. Tip test and T-shape compression test are used to determined friction measurement in cold forging which are used to analyze property of materials.

1 INTRODUCTION

Cold forging is a process in which the shape of metal is changed, by mechanical forces only. In forging, a metal work piece is plastically deformed by pressing, squeezing, or hammering forces. During forging, the material should have sufficient flow properties and ductile properties. Forging is a cost effective way to produce net-shape or near-net shape components such as shafts, axles, bolts, gears and joints. Virtually all metals can be forged. This makes an extensive range of physical and mechanical properties available in products with the highest structural integrity. Forgings are used in high reliability applications where tension, stress, load, and human safety are critical considerations. They are also employed in a wide range of demanding environments, including highly corrosive, and extreme temperatures and pressures.

The conventional backward cup extrusion process with a controllable counterpunch (Fig.1) has been used to access the potential of the system to improve to process robustness as well as tensile stresses in the cup wall. As a target for the robustness analysis bottom height of the press cup is chosen which has to be maintained in very tight dimensional tolerances while process input variable are changing. By means of this experimental tests general possibility of an automated control of cold forging processes. Using a controllable counterpunch a resource and therefore cost efficient manufacturing of thin tabular semi-finished part with sufficient mechanical properties or out of high strength steel suitable for lightweight application should be possible.[1]

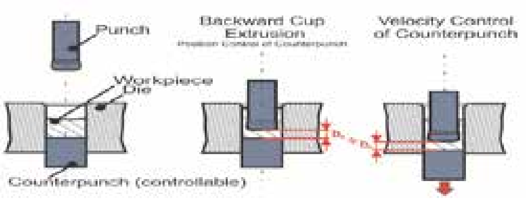

Fig. 1. Sketch of backward cup extrusion with controllable counterpunch

The tip was formed by backward extrusion process in which cylindrical specimen whose diameter was larger than the diameter of the punch and smaller than the diameter of the cylindrical die. Because of this, the initial deformation mode was upsetting and then changed to backward extrusion later once the bulged surface touched the side wall of the bottom die. In this figure the diameter and height of the original specimen used were 30x15 and 10x5 mm2 in the conventional and downsized tip tests, respectively. Using the specimen with the same diameter of the bottom die, the tip can not be formed because of lack of upsetting mode at an initial stage. surface roughness of the bottom die working as counter punch was varied from Ra =0.61 μm to Ra =0.08 μm to better understand its role on the friction behavior and material flow in the tip test using AL6061-O and 2024-O specimens. Four different lubricants such as grease, cooking corn oil, VG32, and VG100 were used in experiments.[4]

As a real industry operation, forward extrusion can be used to evaluate friction in cold forging. because the friction force generated along the surface of container decreases with the billet length, after the die region has been filled with the metal. Then friction factor *m*, or friction coefficient μ, can be determined from the slope of decreasing stroke–load curve of extrusion. T-shape compression test is forward extrusion process. T-shape compression, a new method to determine friction in cold forging, by numerical simulation and experiments. T-shape compression tests with three different lubrication conditions, solid lubricant (phosphate + soap), oil and mixed condition, have been carried out on low carbon steel sample, provides the friction factor *m* and coefficientof these various lubrication conditions.[3]

2 HISTORY

Forging is one of the oldest known metalworking processes. Traditionally, forging was performed by a smith using hammer and anvil.[6] The cold forging process was developed in Germany just before the end of World War II. It was used to produce artillery shells and other ordinance items for the war. After the war, a number of firms in the United States picked up the idea. At first, most of the work here was concentrated on shell manufacture, but it didn't take long for the firms to realize the possibilities of cutting costs in the manufacturing of consumer goods.[5]

By the early fifties, the process had attracted attention from car and truck manufacturers and was being used to produce automotive parts such as brake light receptacles and spark plug bodies. It was a process that could be economically applied to almost any symmetrical part made in large quantities. More than 500,000 tons of steel parts were manufactured by cold extrusion in 1969. By comparison, in 1950 the total was about one tenth of that. [5]

Due to the energy crisis in the 1970's, researchers worked intensely to improve material usage, reduce forging energy, and eliminate machining processes with high precision forging. Since problems such as environment pollution and noise level have become more prevalent, engineers have been researching hydraulics to find the optimum process to take the billet to the final product. Technology has focused on closed die forging and steels designed for cold forming. Closed-die forging technology improves the yield of material usage with the optimal process having no flash and reducing the need for highly skilled workers. Closed-die forging has become a key technology for precision forging of products such as constant velocity joints and bevel gears.[5]

3 EXPERIMENTAL STUDY

3.1 TIP TEST FOR MEASUREMENT OF FRICTION

Downsized tip test was performed with an experimental setup by employing the punch, lower die, and counter punch working as bottom die as shown in Fig 2. To apply the force to the workpiece, MTS machine was used with a maximum load of 100 kN. The forming stroke applied was 3.2 mm and 3.5 mm for AL2024-O and AL6061-O, respectively and constant ram speed of 0.1mm/s was applied during the test.[4]

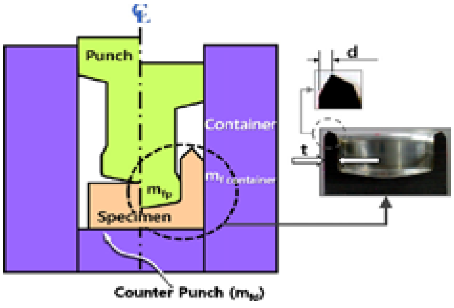

Fig. 2. Schematic of the tip test

To prepare the specimen, commercial AL2024 and AL6061 billets were turned to be a cylindrical bar of 12 mm of diameter and 150 mm in height. After turning, they were heated from room temperature to 415°C and kept at this temperature for three hours. Then, the specimens were cooled at a heat extracting rate of 30°C/hr to 260°C, and finally exposed to air-cooling until reaching room temperature. In order to guarantee uniformity of the test results, enough number of bars was annealed at the same time to avoid material property variation depending on annealing. They were cut off to make a tip test specimen of 10 mm of diameter and 5 mm of height after heat treatment. The dimension of the specimen was measured with vernier callipers to reduce the influence of size difference of the specimen on measurement results of the tip test.[4]

The deformed specimen can be used for measuring the tip distance d as shown in Fig.2 with an optical microscope which has a special feature of extended focal imaging function to integrate pictures of different focuses. The deformed tip distance was measured at four different points because of measured scattering data.[4]

Another important issue for controlling the lubrication is the quality of surface cleanliness. Before applying four kinds of lubricants such as grease, cooking corn oil, VG32, and VG100, the following surface cleaning process was used. At first, the surface of the punch and dies was cleaned by a wiper soaked with acetone to avoid adulteration among the lubricants. Acetone is a solvent for lubricants, hence if there is a residue of acetone on the surface of the punch and dies, it can unexpectedly affect lubrication performance. To remove this residual acetone after surface cleaning, forced air blow was applied on their surfaces by employing a hair dryer. After cleaning, the lubricants were brushed manually.[4]

the environmental factors affect the measured data, the same experimental condition of surface conditions of the specimen and dies, lubricant, temperature, humidity, and deformation speed was maintained during the test. Six experiments were carried out for each lubricant. The maximum stroke was limited up to 3.5 mm in each experiment because of capacity of the testing machine.[2]

In the tip test, centering should be carefully monitored to achieve axi-symmetric deformation. However, it was not easy to perfectly maintain axi-symmetry in experiments. When the specimen, including cutting, lathing and polishing, etc., was not carefully prepared, the edge might be damaged. In this case, the tip was not sharp enough to get precise measurement. To overcome these difficulties of axi-symmetry and measurement, tip distances were measured at four different locations for each sample and were arithmetically averaged.[2]

3.2 T-SHAPE COMPRESSION TEST FOR MEASUREMENT OF FRICTION

T-shape compression includes three parts: punch, cylindrical specimen and die with a V-groove, as shown in Fig.3. The sectional shape of a formed part is 'T-shaped', hence the test is named T-shape compression. In this test, the specimen is first located in the groove as shown in Fig.3(a). During deformation by the top punch, some metal is extruded into the groove and some is upset and moves sideways between the flat surfaces (see Fig.3(b)). The friction force, generated along the wall of groove, restricts metal flow into it, so the height of the extruded part changes with different friction conditions. In addition, this test is well to evaluate the ability of the lubricant. For solid lubrication condition, the cylindrical surface of the specimen was coated with zinc phosphate and soap layer, contact with die and punch directly. For the oil lubrication condition test, the V-groove is filled with the lubricant, so the billet surface is easily lubricated during the test.[3]

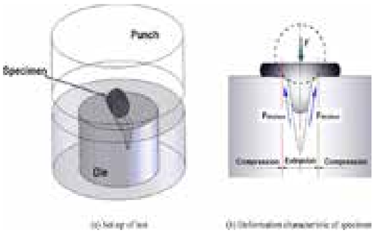

Fig.3. The principle of T-shape compression

3.2.1 Effect of friction condition on load and formed part shape

The whole deformation of specimen in T-shape compression includes two stages-

• In the first stage, the metal is pushed into the die groove and no lateral expansion appears between the punch and flat-top surface of die, due to small contact area between specimen and punch. Also it can be observed that the load changes almost linearly with punch stroke when the ratio of punch stroke to billet diameter increases from 0.15 to 0.43 (see Fig.4).

• In the second stage, the contact region of specimen/punch becomes larger, then the compression of metal occurs between the flat surfaces of the tools, so load will increase shapely.[3]

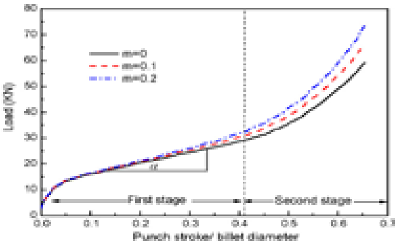

Fig.4. Load curves with different friction factors

Load curves with different friction factors are shown in Fig.4. Results illustrate that the load increases with friction factor and the sensitivity of load to friction factor becomes larger at a higher

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punch stroke. This is because contact area and contact pressure between specimen and die become large with the punch moving down. Thus, the friction increases. Furthermore, in the first deformation stage, the slope of load curve $k = \tan \alpha$ (see Fig.4), changes with different friction factors. Hence, it is a convenient means for determination of the friction condition.[3]

3.3 AUTOMATICALLY CONTROLLED (COLD) FORGING PROCESS

Manufacturing Equipment for Automatic Control of Additional Tool Axes

A tool set developed at IFU enables the integration of one additional hydraulic tool axis with a maximum stroke of 100 mm and a maximum speed of 100 mm/s. The maximum force of the controllable hydraulic axis amount at 500 kN. The hydraulic power unit and the valve bloc were developed by FMB Blickle GmbH with a focus on resource efficiency and online oil condition monitoring. The connected load of 250 kW, the control pumps and servo valves enable the provision of an flow rate of 460 l/min at a maximum pressure of 280 bar suitable for many cold forging processes. The control and the paramaterization of the tool kinematics were developed by press Control Electro-technic and are equipped with a user friendly interface. It provide the communication between the hydraulic unit, servo valves , hydraulic axes and the measured variables during cold forging and the automatic control of hydraulic tool axes and the forming process respectively.[1]

The system for automatic control of cold forging process has been build up in the lab area of institute (Fig. 5).

Fig.5. Hydraulic unit with valve bloc, hydraulic press with tool set and control unit

Table 1. Tool set and technical specifications of experimental equipment

Measuring Equipment	
Punch Load	Strain Gauge
Die Load	Piezoelectric
Counterpunch Load	Piezoelectric
Punch Load	Magneto-Strictive
Counterpunch Stroke	Magneto-Strictive
Ram Stroke	Magneto-Strictive

Hydraulic Unit	
Max. Pressure	315 bar
Max. Flow Rate	460 l/min
Connected Load	250 kW
Servo Valves	4

Measuring equipment shown in Table 1 used for monitoring desired load and strokes respectively. Desired reproducibility of cup bottom height necessitates suitable resolution of measuring equipment. In case of magneto-stricitve measuring of punch and counterpunch stroke a resolution of 5 µm is achievable. For the experimental tests the conventional backward cup extrusion tool set has been mounted on addition tool rack with integrated double-action hydraulic cylinder and integrated stroke measurement. Distance between punch and counterpunch nose or cup bottom height respectively has been monitored using a reference system. Piezoelectric load cells have been placed between counterpunch and double-action cylinder and die and pressure pads respectively. Initial measurement of load cells has been done in mounted condition using a reference load cell.[1]

4 TRENDS IN COLD FORGING

Process Comparison

(A)Conventional manufacturing → Drilling

Disadvantage: High material volume.

(B)Alternative manufacturing: Hollow forging without drilling

Advantage: Minimized material usage→ resource efficient production.

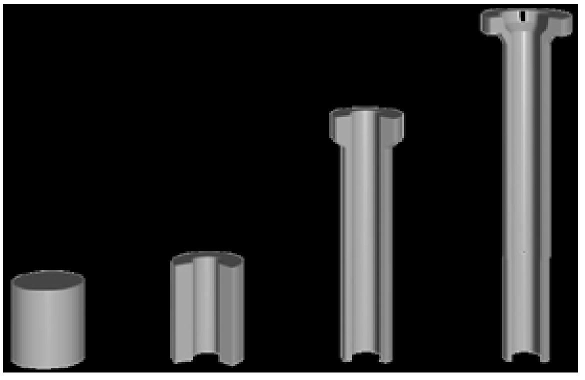

Fig.6. Hollow Forging Hollow Transmission Shaft

•Hollow shaft for double clutch transmission

•Manufacturing sequence includes

Cold forging

Machining

•Hollow shape impossible to manufacture by machining only

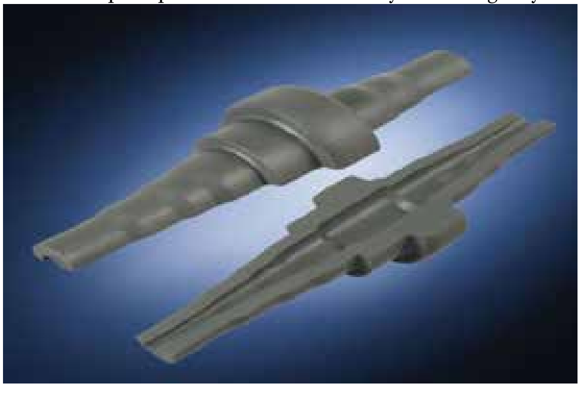

Fig.7. Transmission Shaft Hollow Pinion

•Cold forged pinion with hollow conical head and shaft
•light weight design, Constant wall thickness
•With forged inside hexagon at the end of the shaft

Fig.8. Hollow Pinion

5 RESULT AND DISCUSSION

5.1 TIP TEST

The tip test can be used for determining the friction effect due to relative surface quality between the punch and bottom dies. Material properties obtained by the compression tests. The maximum load values were dependent on the type of lubricants applied.

In Fig.9, the measured tip distance was plotted with the measured load values for various lubrication conditions in the downsized tip test. In this figure, the tip distance and maximum load were non-dimensionalized by the tip thickness t=1.21 mm and 1000 kN, respectively. This test result shows a slope shift from the negative to the positive which is corresponding to the conventional one. This conversion was obtained by changing surface roughness of the counter punch from Ra = 0.61 μm to 0.08 μm for AL6061-O specimen. This is valid for the AL2024-O tip test result as shown in Fig.9 b.[4]

Thus, Ra reduction in the counter punch relative to the punch influenced the slope of linear relationship between the non-dimensionalized tip distance and maximum load. Friction factor ratio (x= mfd/mfp) was determined to be dependent on the surface roughness ratio between the punch and counter punch. These values for AL6061-O and AL2024-O were 0.45 and 0.60, respectively. In order to characterize friction factors at both interfaces at the punch and counter punch, the friction at the sidewall was assumed to be the same as the one of the counter punch.[4]

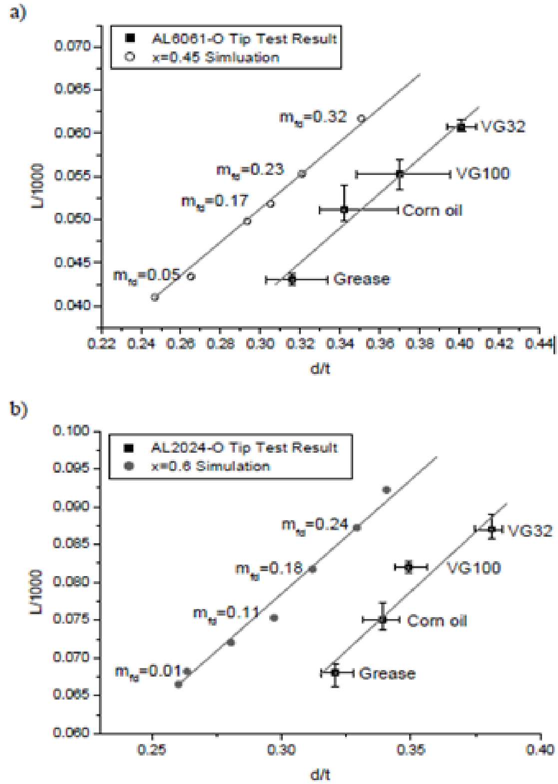

Fig.9. Non-dimensionalized maximum load versus tip distance for
a) AL6061-O and b) AL2024-O

5.2 T-SHAPE COMPRESSION TEST

Fig.10 shows the load curves obtained using the three different lubrication conditions. It can be seen that the forming load from mixed lubrication is a little lower than that from solid lubrication. The load using oil is the largest one because the lubricant is squeezed out of the contact zone by the specimen/tool pressure, so metal-to-metal contact occurs, which induces the large friction. On the contrary, with solid lubrication, the phosphate and soap coating can suffer large normal pressure. Hence a solid layer remains between tool and specimen, which can promote a low friction force during forming. For the mixed lubrication condition, the die is in contact with the phosphate and soap coating when the oil film is pushed out of the contact zone. Therefore, the load curves from mixed and solid lubrication condition are similar.[3]

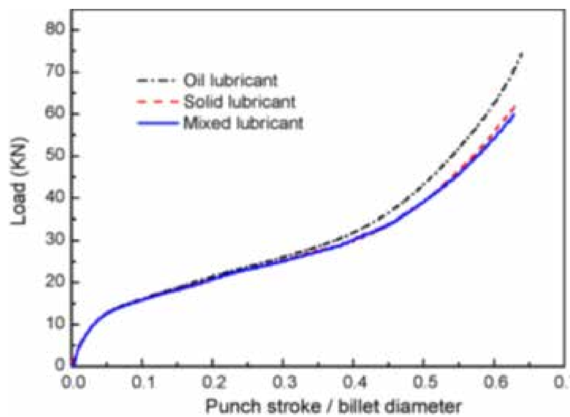

Fig.10. Load curves under different lubrication conditions

5.3 AUTOMATICALLY CONTROLLED (COLD) FORGING PROCESS

For automatically controlled (cold) forging process, tool set with additional hydraulic axis has been used. Raw parts have been machined out of EN AW 1050, shot blasted, coated with zinc stearate. Punch diameter has been chosen as Diameter 16 mm and die diameter was 20 mm. Before the punch touches the raw part counter punch has been pre accelerated to compensate system response time. Maximum forces of counter punch, punch and die depending from velocity ratio a are depicted. It is remarkable, that no force equilibrium is calculable due to the facts that maximumforces are not at the same stroke in any case.

6 CONCLUSON

According to Tip test, it is found that the tip test can be utilized to differentiate the effect of various forming conditions such as surface roughness, deformation speed, and the types of lubricant and material on friction. The effect of surface roughness change of the counter punch is observed by the change of x ratio and slope between the tip distance and maximum load. With higher surface roughness in the counter punch compared to the surface roughness of the punch, the slope became negative. However, with relatively smoother surface roughness of the counter punch compared to the one of the punch the slope is found positive.

According to T-Shape Compression Test,

1. This test induces a complex deformation path, large contact pressure and rather large surface expansion.
2. In this test, the sensitivity of load curve slope to friction condition decreases with increase in the corner radius and V-groove angle in the die.
3. The solid lubricant produces lower friction than oil lubricant, because the oil can be easily squeezed away from the high pressure contact zone. The lubrication performances of solid lubricant and mixed lubricant are similar.

According to Automatically Controlled (Cold) Forging Process, Using a controllable counterpunch punch loads can be reduced in case of an ideal velocity ratio of punch and counterpunch velocity can be chosen. Depending on chosen velocity ratio α, a significant reduction of punch force or punch load respectively is possible using described system.

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