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A Basic Study on the Piston Forging Process

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ABSTRACT

A fundamental study for the production of an internal combustion engine piston by forging is performed through UBET(Upper Bound Elemental Technique) analysis and experiments. In UBET analysis, an optimal preform of the aluminum piston is predicted and the results are compared with the experimental results. The internal flow pattern and and the forging loads according to the differenet friction condition are investigated.

Key Words : engine piston, forging, UBET, model material technique, plasticine

1. Introduction

Aluminum is one of the most important and widely used materials in machine component industries because of its excellent characteristics such as lightness, incorrodibility, and conductivity. These kinds of excellency of aluminum alloys are best consistent with the needs of many types of engine components. Among these components, the piston is a part being operated under severe surroundings and having a great influence on the efficency of the engine. As a moving and power transmitting component, the piston together with the piston rings, must realiably seal the combustion chamber against leakage of combustion gases and lubricating oil under all load conditions.

The structural development of the piston has produced a variety of designs but Fig.1 shows the typical configuration of a piston and the dimensions.[1]

Several methods are available in piston production. Technique based on casting and forging are the representatives, and a further possibility is offered by the use of semifinished material of a powder-metallurgical base.[1] Cast pistons are made by pouring molten aluminum into molds. Forged pistons are made from slugs of aluminum alloy which, when subjected to high forging pressure, flows, or extrudes, into the dies to form pistons. In spite of its excellenct quality, the use of forged piston is limited within some special engines because forged piston, like other forged products, are obtainable at a premium price. Moreover the quality of forged aluminum products through hot process are very sensitive to the temperature control, and this brings about additional diffuculty in piston forging from alluminum alloys.[2]

In additon, due to the complicated configuration arising from thermo-dynamical and mechanical design of piston, casting has been preferred to forging for piston production. The reason is that casting process allows higher degree of freedom than forging in terms of shaping.

However there are problems in the working fields where aluminum piston is produced by casting and additional machining. First of all, the casting process is yielding many defective products. Sometimes the molten material fails to reach the complicated part of piston mold, and it contains bubbles The second problem is that the variability from piece to piece of cast piston products is so high, and therefore property differences within the same casting may be very pronounced.

Generally, forgings offer a high strength-to-weight ratio, toughness, and resistance to impact and fatigue This fact is especially important because reduction in weight is directly related to increase in output because of the inertia force. In additon for very large quantities, cost per piece made by casting is higher than parts made by a more expensively tooled method.

Therefore, when we control the process design and structural design of the engine piston adequately, we can produce the price-competitive pistons as well as higher quality pistons made by forging process.

In this study, as a way of basic research for the piston forging, firstly a simplified model of piston configuration is analyzed through UBET(Upper Bound Elmental Technique) and experiments on this model using model matrial plasticine(by Hurbutt, England) are done. The optimal preform and the dimensions of final products according to this preofrm are checked, and the internal flow pattern of forged piston and the forging loads are investigated.

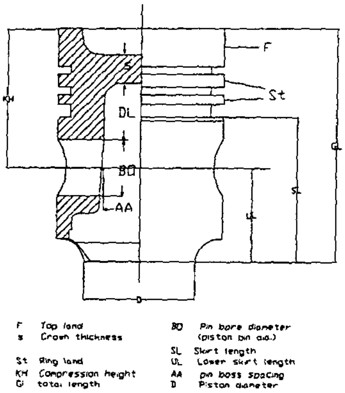

Fig.1 Typical Piston Dimensions and Terms

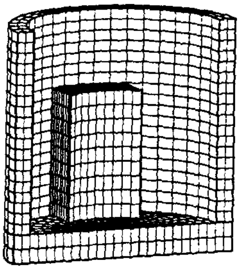

Fig.2 Simplified Model of Piston

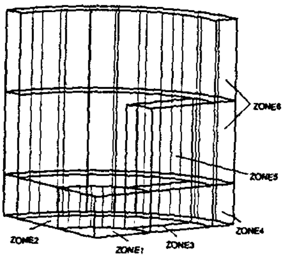

Fig.3 Layout of Element Division

2. Theorectical Analysis and Experiments

2.1 UBET Simulation of Piston Forging

Using UBET(Upper Bound Element Technique) we analyzed the forming process of the piston. To make it easy to analyze the piston forging, we simplify its configuration as shown in Fig.2. This shape of product can be obtained by two processes. First axisymmetric backward extrusion, then addtional forging process to reach the final product. In this paper only the latter forging process is simulated. Due to the symmetry, only one forth of total part is analyzed. Fig.3 shows the layout of element division for the UBET simulation. In the cylindrical coordinate, the kinematically admissible velocity field for each element is as follows.[3]

(A) ZONE 1

$$U_z = A_1 Z + B_1,\quad U_\theta = 0,\quad U_R = -\frac{1}{2} A_1 R$$

,where

$$A_1 = -\frac{U_0}{Z_2 - Z_1},\quad B_1 = \frac{U_0 Z_1}{Z_2 - Z_1}$$

(B) ZONE 2

$$U_z = A_2 Z + B_2,\quad U_R = C_2 R + D_2$$

$$U_\theta = -[(A_2 + 2C_2)R + D_2]\theta + E_2$$

,where

$$A_2 = A_1,\ B_2 = B_1$$

$$E_2 = [(A_2 + 2C_2)R + D_2]\frac{\pi}{2}$$

$$C_2 = \frac{1}{2(R_1^2 - R_2^2)}(A_1 R_1 + A_4 R_2) + \frac{E_4}{R_2(R_2 - R_1)}$$

(C) ZONE 3

$$U_z = (A_3 R + B_3)(Z - Z_1),\quad U_R = C_3 R + D_3$$

$$U_\theta = -[A_3 R^2 + (B_3 + 2C_3)R + D_3]\theta + E_3$$

,where

$$B_3(R) = -A_3 R + A_2 - \frac{D_2 \alpha}{R \sin^{-1}\frac{t}{R}} - \frac{(A_2 + 2C_2)\alpha}{\sin^{-1}\frac{t}{R}}$$

$$C_3 = C_2,\ D_3 = D_2,\ E_3 = 0$$

(D) ZONE 4

$$U_z = A_4 Z + B_4,\quad U_\theta = 0,\quad U_R = -\frac{1}{2} A_4 R + \frac{E_4}{R}$$

, where

$$A_4 = \frac{U_b}{Z_2 - Z_1},\quad B_4 = -\frac{U_b Z_1}{Z_2 - Z_1},\quad E_4 = \frac{1}{2} A_4 R_3^2$$

(E) ZONE5

$$U_z=(A_3R+B_3)(Z_2-Z_1),\ U_\theta=0,\ \ U_R=0$$

(F) ZONE6

Rigid body which is backward extruded at the velocity if U_b

2.2 Experiments with Model Material Plasticine

Determining process steps and tool designs for plastic forming processes is not an easy task. It can be especially difficult when processes involving large and complicated flow are to be controled. In these cases, the theoretical methods become better when they are aided by experiments. But experiments carried out in the production tool itself require large-scale investments and occupation of a production machine for experiments. Due to these reasons experiments technique based on model materials such as plasticine, clay, wax, and lead, etc are well used.[4]

In the experiments plasticine as a model is used to vizualize the metal flow for the simplified piston.

The effective strain and stress relationship of plasticine is given as follows.[5] We asume that the flow stress of plasticine is dependent only on effective strain.

$$\bar{\sigma}=0.17797\,\bar{\varepsilon}^{\,0.0822}$$

The specimens of plasticine for piston forging are laminated with two colors(white and black) so that the metal flow inside the material is visualized, after being kneaded enough to remove air bubble in plasticine.

The dies shown in Fig.4 are used. To make it easy to divide the plasticine product from the container, we prepare two halves of split container which can be assembled with volts.

The experiments are performed with M.T.S whose maximum load is 25ton at a constant ram velocity(1mm/s). In the backward exrusion processes the effect of lubricant is very important so we use two kinds of lubricants(talc powder and vaseline).

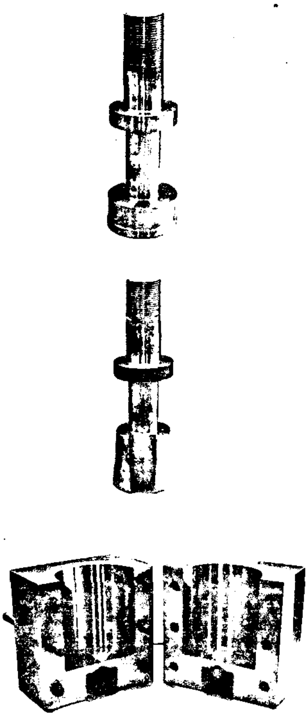

Fig.4 Container and Punch

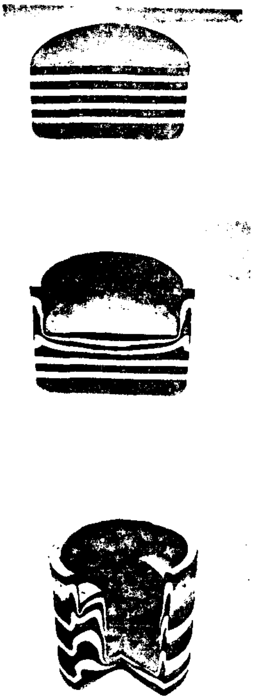

Fig.5 Billet, Preform and Product

2.3 Results and Discussion

2.3.1 Dimensions of final products

To get to the final shape, we will start with a cylinder specimen($\phi 40\times 37$) whose dimensions are obtained by volume constancy condition.

When we follow two processes, first axisymmtric backward extrusion using Punch 1 in Fig.4 and then 3 dimensional backward extrusion using Punch 2 in Fig.4, we can get the product of final shape. Fig.5 shows the initial billet, preform, and the final extruded product. So the dimensions of final product can be controlled by the amount of axisymmetric backward extrusion. This means that preparing the adequate preform is the critical parameter to get the final product.

From the UBET simulation we can find the optimal preform. The results of simulation show that the travel distance of axisymmetric backward extrusion punch(Punch 1 in Fig.4) is 8mm from the top of the initial billet, in other words the initial billet is axisymmetrically backward extruded by 28.8mm at first process we can obtain the most desirable dimensions of forged products at second process.

Fig.6 and Fig.7 shows the dimensions of final extruded products according to the dimension of preform. Even if there is difference of the internal flow pattern due to the different lubricants(Talc Powder and Vaseline), the difference of the outer dimension due to the difference of lubricants is negiligible. Fig.8 shows final extruded products.

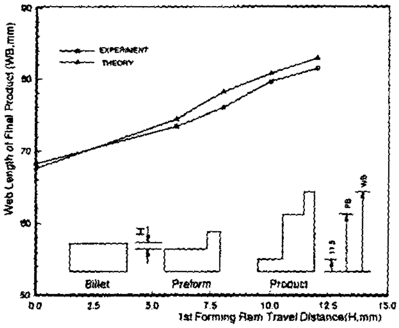

Fig.6 Dimensions of Final Products(Web)

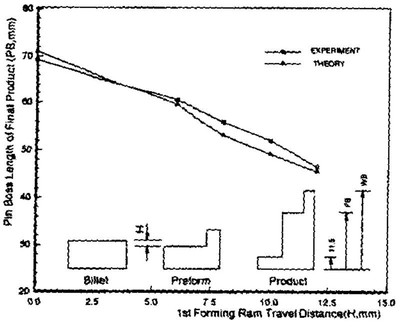

Fig.7 Dimensions of Final Products(Pin Boss)

Fig.8 Extruded Products

2 Flow Characteristics

As mentioned in Section 2.3.1, the outer dimensions of extruded products were almost independent of the friction condition. However, the internal flow pattern of the products show differently as in Fig.9 and Fig.10. The product in Fig.9 is extruded from the initial billet, in which case (A) is those obtained by using talc powder and (B) is those by using vaseline. In these two products, the flow pattern at the pin boss part is quite different from each other. In the case where we used talc powder, the velocity of inner part of pin boss is greater than outer part because the material flow is constrainted at the outer part due to the large friction between the material and the wall of the container. On the other hand, the inner part of the supporter does not undergo such a large friction, so moves upward more easily. However, in case (B) where the lubricant vaseline, whose friction factor is relatively small, is used, even contact area with container wall is large, the friction does not constraint to flow very much, and the velocity of the outer part of the pin boss greater than inner part.

(A) LUB: Talc Powder (B)LUB:Vaseline

Fig.9 Extruded Product from Initial Billet

(A) LUB: Talc Powder (B)LUB:Vaseline

Fig.10 Extruded Product from Preform

Fig.10 shows the internal flow pattern of the extruded product using preform which we obtain by axisymmetrically backward extruding the initial billet by 28.8mm((A) by talc powder and (B) by vaseline). The difference of flow pattern is similar to that of previous case shown in Fig.9 A. But special attention is needed to check the folding at the outer part of the pin boss. Through close examination the folding has not occurred yet, but as ffriction increases between container wall and the material and inner part of pin boss goes upward faster than outer part the possibilities are that there will be folding which will result in bad effect on product.

2.3.3 Forming Load

Fig.11 shows the stroke-load diagram for two types of forgings and two kinds of lubricants. We compared forging load of axisymmetric backward extrusion to that of 3-dimensional backward extrusion by Punch 1 in Fig.4 using the optimal preform mentioned in Section 2.4.1 In the case of piston forging the lubricant played an important role to reduce the forging load.

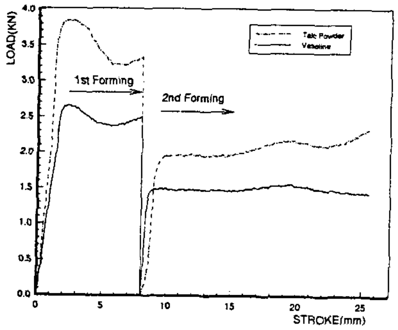

Fig.11 Load-Stroke Diagram of Piston Forging

3. Conclusions

For the production of piston used in internal combustion engine, forging process is suggested. By UBET the optimal preform form the initial cylinder billet and the dimensions of final product are predicted. And model material experiments using plasticine is performed to verify the simulation, to visualize the materal flow, and to conform the adaptability of forging process to piston manufacturing. Through this study we come to the following conclusions

1. The conventional production method of piston by casting can be possibly replaced with forging.
2. To obtain the final shape of piston, preform by axsymmetric backward extrusion is used, and the dimension control of preform is the key parameter to reach the needed final dimension.
3. In the processes for manufacturing piston suggested in this study, the desirable shape of ring boss is available under the relatively low firction condition.

To check the advantage of forged piston over cast piston, further study by real material experiments is necessary.

Acknowledgement

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