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Powder Forging of Rapidly Solidified Al-Si Alloy with Back Pressure

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Abstract Powder forging with a back pressure was investigated for production of automobile and compressor parts made of a rapidly solidifed Al-Si alloy powder. Disk-shaped green compacts made of a rapidly solidified Al-Si alloy powder were hot forged, and hubs were formed by loading back pressure on their top. The influences of the back pressure and die temperatures on forgeabiliy and properties of parts made of a rapidly solidified Al-Si alloy powder were examined. This method was also applied to the production of a scroll part. The results of these studies are summarized as follows:

1. A back pressure on the hub top is very effective for consolidation and preventing crack formation in the hub.
2. When a back pressure less than 98 MPa is applied, the forging pressure increases by the same amount of the applied back pressure. With more than 98 MPa, the forging pressure increases further due to an increased friction at the hub side.
3. Die temperatures higher than approximately 670K are needed in order to consolidate well the hub top without cracks.

1. Introduction

Recently, high performance, light weight and thin compressor and automobile parts are increasingly important. Rapidly solidified hypereutectic Al-Si alloys are attractive for these applications because of their light weight, high strength, wear resistnace and low thermal expansion coefficient.

For rapidly solidified aluminum alloys the extrusion method is the conventional consolidation process. However, the extrusion is a complicated process, and besides it is difficult to produce complex shape parts. On the other hand, the powder forging is a simple process [1], and it can be used to produce complex shape parts economically.

In this report, the powder forging with a back pressure was applied to consolidate a rapidly solidified hypereutectic Al-Si alloy powder and to form axisymmetric hubs. The influence of the back pressure and die temperatures on forgeability and properties of the Al-Si alloy parts were examined. Furthermore, this method was applied for the production of the scroll part, which is main component of a scroll-type compressor.

2. Experimental Procedures

An air atomized Al-Si alloy powder (-100 mesh) was used in this investigation and Table 1 shows its chemical compostion. Disk-shaped green compacts with 44 mm in diameter and 50g of weight were prepared by the rigid die pressing. These compacts were heated at 753K for 1.8ksec, and hot forged with a back pressure to form plates with the axisymmetric hubs. The plate and hub were 45 mm and 14 mm in diameter, and about 10 mm and 20 mm in height, respectively.

Table 1. Composition of a rapidly solidified powder used in this study, in mass percent

Si	Cu	Mg	Fe	Al
24.6	2.8	1.1	1.1	balance

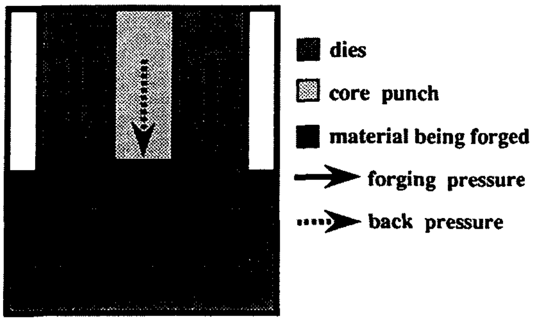

Fig. 1. Schematic of forging with a back pressure to form the hub.

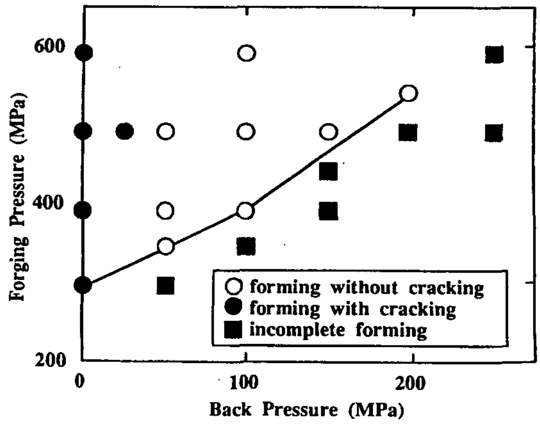

Fig. 2. The relationship among forging pressures, back pressures and the hub formation when the preform and die temperature is 753K.

A schematic illustration of the forging press is shown in Fig. 1. When a green compact is pressed by the upper punch with the main hydraulic cylinder, the core punch in the upper punch is also pressed by another hydraulic cylinder. The core punch can be moved by the material flow. During forming the hub, the hub top is pressed by the core punch all through the operation. In other words, during the hub is being formed, simultaneously a force preventing the material flow is applied to the hub top by the core punch.

The forging pressure applied by the upper punch and the back pressure with the core punch were set to desirable values at any given time. The preforms were pressed for less than 30 seconds. The die was heated at from 423 to 753 K. The influences of the back pressure and die temperatures on forgeability of the rapidly solidified Al-Si alloy powder were examined. The consolidated samples were T5 heat treated and then evaluated.

This type of experiment was made on the production of the scroll part. In this case, the core punch was set in the upper punch and scroll-shape punch was set in the lower die, and they were pressed by hydraulic cylinders except the main cylinder.

3. RESULTS AND DISUSSION

3.1. The relationship between back pressure and forgeability

Fig. 2 shows the relationship among forging pressures, back pressures and the hub formation when the prefom and the die temperature is at 753 K. The solid line shown in Fig. 2 represents the conditions in which 30 seconds pressing are needed to form the hub. This indicates that the forging pressure increases by the some amount of the back pressure applied in the case of back pressure of 98 MPa or less. When the back pressure applied is more than 98 MPa, a contribution of the hub side's friction is seen. The increased friction at the hub side is attributed to an enhanced contact pressure on the hub side. In the case of back pressure of 98 MPa or less, this effect is not seen. In Fig. 2, the hub formation times are shorter for the region far above from the solid line. In the case of the forging pressure of 588 MPa and the back pressure of 98 MPa, the time required is 3 seconds.

It appears that in cases of applied back pressures of 49 MPa or more, the back pressure prevents the crack formation in the hub, which is independent of the forging pressure as shown in Fig. 2. The forged samples with or without a back pressure are shown in Photo 1. When the back pressure of 49 MPa was applied, there is not seen any visible defects as shown in Photo 1. On the other hand, when the back pressure was not applied, there are many cracks on

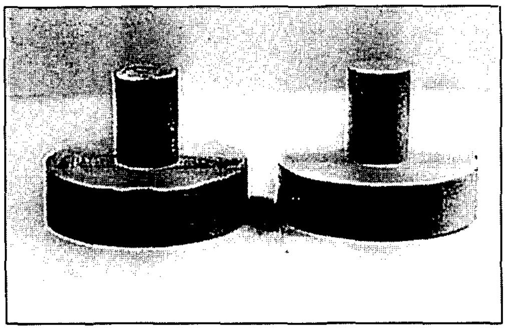

Photo 1. Appearance of the samples; the forging pressure of 490 MPa and the back pressure of 0 (left) and 49 MPa (right).

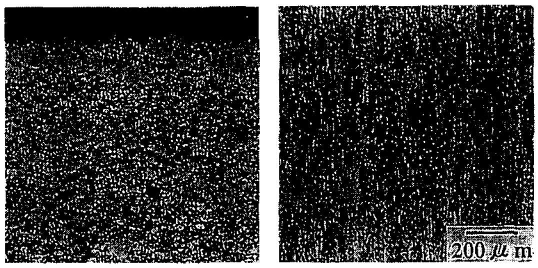

Photo 2. The grain flow patterns of the top of the hub (left) and the root of the hub (right) illustrated by optical micrographs.

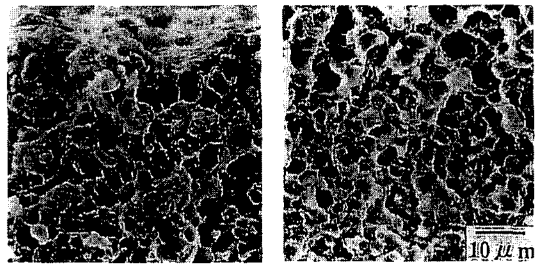

Photo 3. Fractured surfaces of the top of (left) and the inner part of the hub (right) illustrated by SEMs.

the top and the side of the hub. The back pressure is considered to be effective for preventing the crack formation during compressing the hub top, by enhancing the hydrostatic pressure and promoting material filling near the hub root corner.

3.2. The properites of the forged parts

The T5 heat treated samples with no crack were evaluated for hardness and transverse rupture strength, which are shown in Table 2. The forging pressure and the back pressure do not affect much the properties as shown in Table 2. Hardness of the hub topics slightly smaller than those of other positions.

The grain flow patterns examined by the optical micrographs for a region near the top of the hub and near the root of the hub are shown in Photo 2. Round prior particle boundaries can be seen near the hub top, which indicates that particles were not deformed much. On the other hand, long and narrow boundaries due to original particles can be seen near the hub root, which indicates that particlees were deformed. Also, scanning electron micrographs of fractured surfaces of the top of and the inner part of the hub are shown in Photo 3. Both were fractrued in a ductile and inter-granular manner. They were not fractured at prior particle boundaries. Therefore, it is concluded that particles at the hub top are well consolidated and combined with each other regardless of their small deformation.

A consolidation mechanism of forging with the back pressure may be as follows. In an early stage of forging, the plate part is densified. In the case of insufficient densification of the plate, loss in the forging pressure is large and the pressure transmission is not sufficient enough to make powder flow

Table 2. The properties of the T5 heat treated samples

Forging pressure (MPa)	Back pressure (MPa)	Transverse rupture strength (MPa)	Hardness (HRB)			
			the hub		the plate	
			top	inner	surface	inner
588	98	96.2	85.4	86.7	87.5	87.0
490	49	93.1	86.8	89.0	87.1	87.8

into the hub cavity against the back pressure. After the plate was well densified, the forging pressure is transitted effectively, and the material can move into the hub cavity. The main step in this process is considered to be this plate densification and the shearing by the extrusion into the hub cavity. The hub top is considered to be consolidated directly by the back pressure. The flow stress of this material is 18 MPa, which is evaluated by compressing forged specimen at 753 K, with strain rate of 10^{-2}/sec. It is much less than the back pressure (49 MPa), and particles are considered to be consolidated easily.

3.3. The influence of the die temperature

Preforms preheated at 753 K were pressed in less than 30 seconds at die temperatures of 423 k, the hub without cracks was not prepared with the forging pressure of less than 883 MPa and the back pressure of less than 245 MPa. At 573, 623 and 673 K, there were no visible crack when back pressure of 49 MPa or more were applied. at 573, 623 and 673 K, and when 49 MPa of back pressure was applied, the forging pressure of 588, 466 and 392 MPa or more were needed to form the hub, respectively. However, samples made at 573 and 623 K, hardness of the hub top is less than that of one prepared at a die temperature of 753 K as shown in Table 3. At 623 and 673 K, scanning electron micrograhs of fractured surfaces of the hub top are shown in Photo 4. In the samples made at 673 K, the hub top was fractured in a ductile and inter-granular manner just as ones prepared at 753 K. On the other hand, the hub top prepared at 623 K was fractured at prior particle

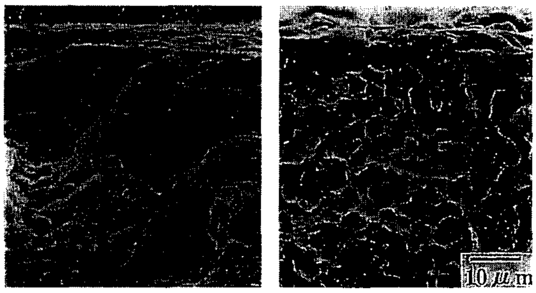

Photo 4. Fracutred surfaces of the hub top illustrated by SEMs. Specimens wre forged at die temperatures of 623 K(left) and 673 K (right), respectively.

boundaries. This fracture pattern is alomost the same as that of samples with a die temperature of 573 K. However, the part benearth approximate 1 mm or more from the hub top was fractured in a ductile manner. The lower hardness vlaues of samles prepared at 573 K is considered to be due to an insufficient combination of the particles. This is due to a decrease of elongation and hardening of particles because of the temperature drop during consolidating the hub top. Therefore, it is concluded that the die temperature is an important parameter for near net shape forging and die temperatures of about 673 K or higher are required to consolidate fully the hub top.

3.4. Application

The forging with the back pressure was applied to the production of the scroll part. As shown in Fig. 3, the core punch was set in the upper punch and a pressure of 49 MPa was applied by a hydraulic cylinder. Also, a scroll-shaped punch was set in the

Table 3. Hardness of the hub top made at some die temperatures

Die temperatures (K)	Forging pressure (MPa)	Back pressure (MPa)	Hardness of hub	
			top (HRB)	inner (HRB)
573	588	98	incomplete	formation
573	784	98	81.1	85.5
573	882	147	81.2	86.8
623	588	98	82.0	85.8
673	588	98	85.0	87.0
753	588	98	85.4	86.7

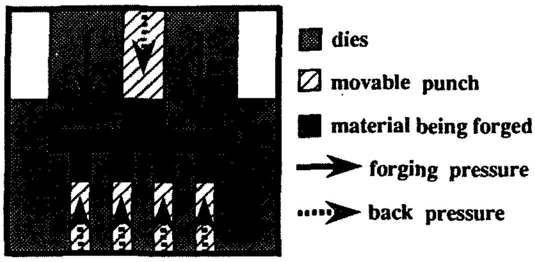

Fig. 3. Schematic of the scroll part forging.

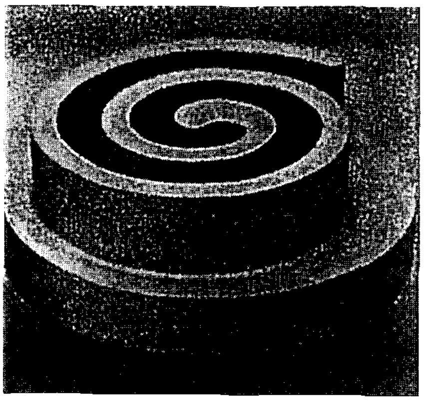

Photo 5. Appearance of the scroll part which was forged with back pressure.

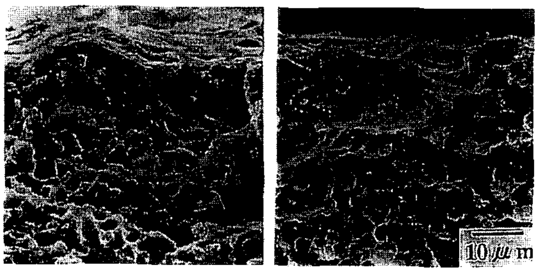

Photo 6. Fracturesd surfaces of the hub (left) and the scroll-shaped plate(right) tops illustrated by SEM.

lower die and a pressure of 49 MPa was applied by another hydraulic cylinder. Disk-shaped green compackts with 68 mm in diameter and 170 g of weight were prepared by the rigid die pressing. Green compacts and dies were heated at 753 and 673 K respectively. Preforms wre forged with a forging pressure of 441 MPa and T5 heat treated. A forged sample is shown in Photo 5. There is no visible defect in the part. And the hub and the scroll-shaped plate tops were well consolidated shown in Photo 6.

IV. Conclusions

The powder forging with a back pressure was investigated in order to preoduce parts with a hub from a rapidly solidified hypereutectic Al-Si alloy powder. The influences of the back pressure and die temperatures on forgeability and properties of parts made of rapidly solidified Al-Si alloy powders were examined.

1. A back pressure on the hub top is very effective for consolidation and preventing cracking of the hub.

2. When a back pressure applied is less than 98 MPa, the forging pressure is increased by the same amount of back pressure. When more than 98 MPa is used the forging pressure is increased further due to an increased friction at the hub side.

3. The die temperature are needed to be above approximately 670 K in order to consolidate the hub top well without cracking.

Reference

1. M. Otsuki, S. Kakehashi, T.Kohno: Advances in Powder Metallurgy 1990., **2** 345 (1990).