Vol.9 No.3 Sept. 2002
Article ID: 1005-9784(2002)03-0159-06

Squeeze casting of Al-Cu alloy

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Abstract: In order to use the cast method to replace forge method in producing the load-bearing wheel used in certain heavy duty vehicle, simplified and reduced size load-bearing wheels were squeeze cast and studied using Al-Cu alloy. Tensile properties, hardness, microstructures and morphologies of the squeeze-cast wheels were investigated. The results show that the finer microstructure, higher density, strength, toughness and hardness were achieved through the squeeze casting. Ultimate tensile strength of 428 MPa, yield strength of 360 MPa, elongation of 13.1% were achieved for T5 heat-treated squeeze-cast wheels. The Brinell hardness of squeeze-cast wheels is from HB 120 to HB 137.

Key words: squeeze casting; Al-Cu alloy; mechanical property; wheel
Document code: A

1 INTRODUCTION

Squeeze casting provides an alternative method for high performance parts forming. Desirable features of both casting and forging are combined in this hybrid method, which is also known as liquid metal forging[1]. Four steps are involved in the squeeze casting process: (a) A measured quantity of molten metal is poured into an open preheated female die cavity located on the bed of a hydraulic press. Some initial cooling of the metal occurs before the pressure added; (b) The upper die or punch (male) is then lowered, coming into contact with the liquid metal and sealing the metal within the die, and continues to travel until the applied pressure has reached the desired level. The time elapses before the application of pressure needs to be minimized to prevent premature solidification of the metal in the die; (c) The pressure is maintained until all the molten metal has solidified. During this period the metal is forced into intimate contact with the die surfaces; (d) The upper punch returns to its original position and the solidified casting is ejected[2, 3]. Provided that the die cavity and the feeding system are correctly designed, the applied pressure is large enough to feed shrinkage porosity and to reduce or eliminate the development of gas porosity. With good physical contact between the solidifying melt and the die, squeeze castings exhibit fine surface detail with high tolerances and minimum need for finish machining[4].

The load-bearing wheel, made by aluminum alloy, is an important part in certain heavy duty vehicle, and the ultimate tensile strength (τ_{UTS}) is not less than 380 MPa, the yield strength (σ) is not less than 320 MPa, and the elongation is not less than 8%.

The purpose of the present study is to investigate the use of the squeeze casting technology in producing the simplified and reduced size load-bearing wheel, and lay a basis for the mass production of the real size cast wheels.

2 EXPERIMENTAL

2.1 Alloy

The alloy used in this investigation is a patented material (HGZL-01) developed by our research group on the basis of Al-Cu alloys by opti-

Foundation item: The National Defence Science and Technology Research Foundations(No.99J12.1.1.JW1606)
Biography of the first author: CHEN Wei-ping, Dr., professor born in August 1959, majoring in material processing engineering.
Received date: March 1, 2002

mizing their chemical compositions and microstructures[5,6]. HGZL-01 alloy contains 4.5-6.0 Cu, 0.20-0.80 Mn, 0.20-0.80Mg (mass fraction, %), certain content of zirconium, vanadium, and remainder is aluminum. The alloy has good mechanical property and moderate castability.

2.2 Smelting and pouring

HGZL-01 alloy was melted in an oil burning furnace. About 50 kilograms of qualified molten metal was prepared, and about 20 wheels and 6 separate gravity cast tensile bars were produced in each batch. Aluminum ingot, Al-Mn, Al-Zr and Al-V master alloys were charged to the preheated crucible at the beginning of smelting. The preheated Al-Cu master alloy was charged into the bath when the temperature of the molten metal reached 720 ℃. Stir the bath for three minutes. After charging the commercial refiner, leave the bath alone for eight minutes and then discard the floating slag. A little commercial covering flux was scattered on the surface of molten metal to prevent oxidization and gas-absorption. After magnesium was charged, leave the bath alone for five minutes, and the molten alloy was ready for pouring at 730 ℃ to 740 ℃. Three wheels were cast first in the die without pressure application; three tensile bars were cast next in a steel permanent mold; about 17 wheels were cast later by squeezing at 45 MPa, another 3 tensile bars were cast in permanent mold.

2.3 Heat treatment

The wheels and tensile bars were heat treated in a well-type electric furnace. T5 and T6 heat treatment conditions were used in this investigation. Wheels and tensile bars were solution heat treated for 12 h at 538 ℃ and rapidly quenched into water. 24 h after quenching, aging was carried out at a temperature of 160 ℃ for five hours in the case of T5, and at a temperature of 175 ℃ for eight hours in the case of T6.

2.4 Specimen preparation and property measurement

Wheel specimens were cut vertically and horizontally from heat-treated cast wheel. All specimens were machined to standard small tensile bars with a gage length of 25 mm and a diameter of 5 mm. Surfaces of tensile bars were ground before testing. Tensile testing was carried out on a computer-controlled CMT5105 material testing machine equipped with 100 kN load cell. Hardness testing was carried out using a steel ball of diameter 2.5 mm, load of 612.5 N and dwell time of 30 s.

3 PROCESSING PARAMETERS

Effective squeeze casting depends upon satisfactory control of key process parameters. Product quality and production economies are both influenced by the interrelated functioning of critical parameters including ultimate applied pressure, pouring temperature, waiting time, dwell time and die coatings[7].

1) Ultimate applied pressure

Applied pressure is an important parameter in squeeze casting process. It directly affects the squeeze-cast part's mechanical property, defects, microstructure, segregation and melting point etc[8]. Low applied pressure leads to unsatisfactory properties, while too high pressure will damage the die and require large tonnage equipment, and the performance of casting cannot be improved significantly.

Considering that our final goal is to squeeze-cast the real size load-bearing wheel, which has a projection area of about 350 000 mm^2, on a 16 MN press machine, the ultimate applied pressure of 40-45 MPa is used in this investigation.

2) Pouring temperature

Too low or too high pouring temperature will give adverse effect on the shape forming and the performance of casting. Low pouring temperature leads to premature solidification and requires large pressure. High pouring temperature often causes shrinkage in casting[9,10]. Pouring temperature in this investigation is 720-730 ℃.

3) Waiting time

The waiting time, controlled by the downward velocity of the machine, in this investigation was as long as 7-10 s. Too long a waiting time brought about unwanted effect on strength and ductility of the casting, and caused non-eliminatable gap on the former liquid surface prior to pressure application[11].

4) Dwell time

Dwell time is decided by the thickness of casting. Shorter dwell time is expected on the assurance of proper shape-forming and solidification. Too short a dwell time may lead to shrinkage in casting, on the contrary, too long a dwell time may lengthen the productive cycle, large deformation resistance and damage the die seriously[12]. The thickness of wheel casting is about 10 mm, and the dwell time used was 8-15 s.

5) Die temperature

Operating die temperatures must strike a balance between the need for sufficient heat to prevent premature solidification and the prevention of soldering between the component and the die which can be pronounced above 350 ℃[12]. In this investigation, the die was preheated to 300 ℃ in a well-type electric furnace. But die temperature would decrease to 150-200 ℃ due to the heat loss in transportation and assembly. It increased to about 300 ℃ after 2-3 castings. Die temperature gradually stabilized between 250 and 350℃ after consecutive castings.

6) Die coatings

Die coating is a key factor in successful operation. The main role of die coatings is to (1) protect the die, (2) improve visual quality of casting and (3) separate casting from die[13]. Oil-graphite coating, which was a mixture of 5% (volume fraction) oil and 95% graphite with a size of 200-300 grit, was used in this investigation. Coatings were brushed directly on the working surface of the die.

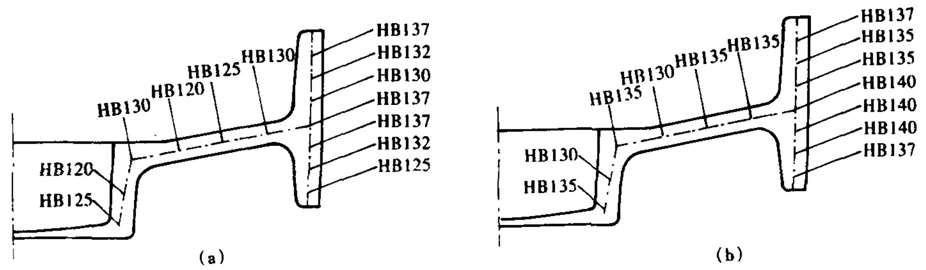
4 RESULTS AND DISCUSSION

Table 1 lists mean mechanical property data of squeeze-cast wheel. As a comparison, tensile property of both separately cast tensile bar and gravity die cast wheel are also given in Table 1. It was deduced from Table 1 that tensile properties of squeeze-cast wheel were higher than those of separately cast tensile bar: 3%-5% increase in τ_{UTS} and 5%-9% increase in elongation (δ). And the squeeze-cast wheels were significantly more ductile than the gravity die cast wheels. For example, the squeeze-cast wheel had an elongation of 13.1% (T5) and 11.3% (T6), respectively, compared to those of 10.5% and 9.4%, respectively. The increase in elongation reached 24.8% and 20.2% in T5 and T6 heat-treated condition, respectively. Meanwhile, τ_{UTS} in squeeze-cast wheels increased 8.1% and 8.6% than the one in gravity die cast wheels in T5 and T6 heat-treated condition, respectively.

The applied pressure increases the heat transfer coefficient between the die and the casting, and this leads to relatively short solidification time, high cooling rates, and fine microstructures[14]. In addition, the applied pressure is high enough to eliminate or at least minimize shrinkages in casting and obtain almost full density casting. Compared with tensile bar, the wheel has complex structure and larger dimensions, and they brought about difficulties in filling and feeding. These will result in worse property in gravity cast wheel compared with those in gravity cast tensile bar. The causes mentioned above as well as the low applied pressure, less than 50 MPa, led to a limited increase in tensile property of the squeeze-cast wheel compared with those of the separately cast tensile bar.

Table 1 Mechanical property data

Sample	Cast method	Heat treatment	τ_{UTS}/MPa	σ/MPa	δ/%
Wheel specimen (Horizontal)	Squeeze	T5	428	360	13.1
Wheel specimen (Vertical)	Squeeze	T5	422	348	12.7
Wheel specimen (Horizontal)	Gravity die	T5	396	320	10.5
Separately cast tensile bar	Permanent mold	T5	413	335	12.0
Wheel specimen (Horizontal)	Squeeze	T6	440	395	11.3
Wheel specimen (Vertical)	Squeeze	T6	435	384	11.1
Wheel specimen (Horizontal)	Gravity die	T6	405	365	9.4
Separately cast tensile bar	Permanent mold	T6	416	375	10.6



(a)—T5 heat-treating condition; (b)—T6 heat-treating condition

Fig. 1 Cross-section hardness distribution in squeeze-cast wheel

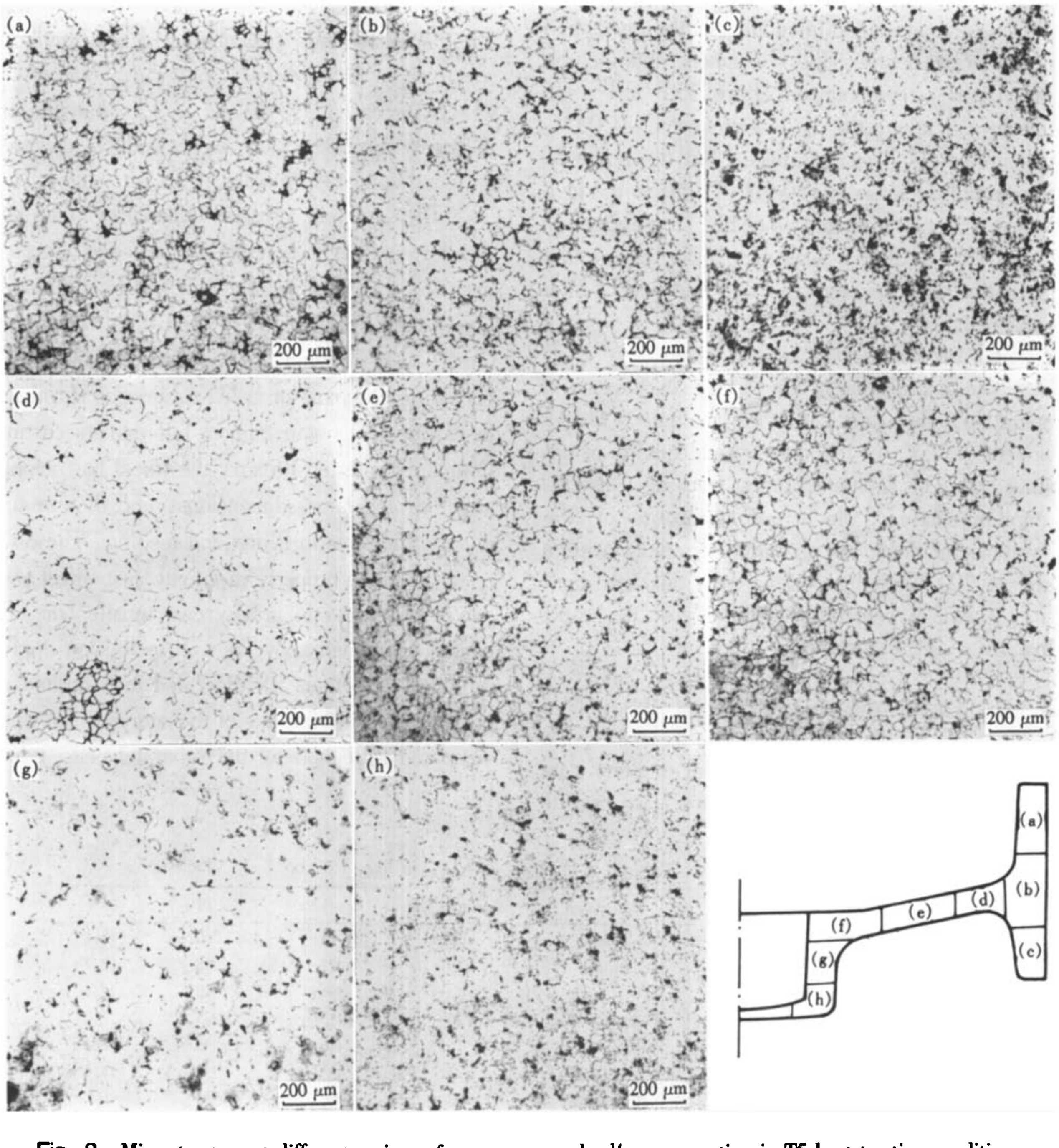


Fig. 2 Microstructure at different regions of squeeze-cast wheel's cross section in T5 heat-treating condition

Hardness distribution on cross-section of the T5 and T6 heat-treated squeeze-cast wheel are exhibited in Fig. 1. Microstructures at different regions of the T5 heat-treated squeeze-cast wheel are given in Fig. 2. The cast tensile bar in the T5 heat-treating condition is shown in Fig. 3. Comparison of SEM fracture surface morphologies between the squeeze-cast wheel and the gravity die cast tensile bar in the T6 heat-treating condition are given in Fig. 4. It can be observed from Figs. 2-4 that the squeeze-cast wheel had a fine, well-distributed, and dense microstructure. However, because their loading and solidification conditions were not the same, different regions had different microstructures. For example, no porosity and very little shrinkage were observed in region (d) and (e) minor porosity and a little shrinkages existed in region (b) because the region was located on the hot spot of the casting. A little shrinkage existed in region (c) because the effective pressure at that region is the least. And we can not conclude that there is a relationship between shrinkage and hardness. That is to say, microshrinkages in squeeze-cast parts were very small in size and well distributed, so it exerts very little influence on the mechanical property of the castings. On the contrary, porosity or shrinkage in gravity die cast parts were large in size and concentrated at the center position (Fig. 3), which influences the mechanical properties of the casting greatly.

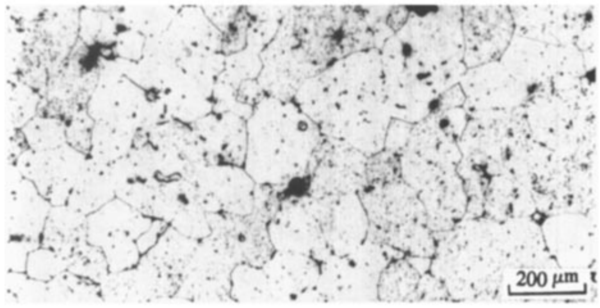
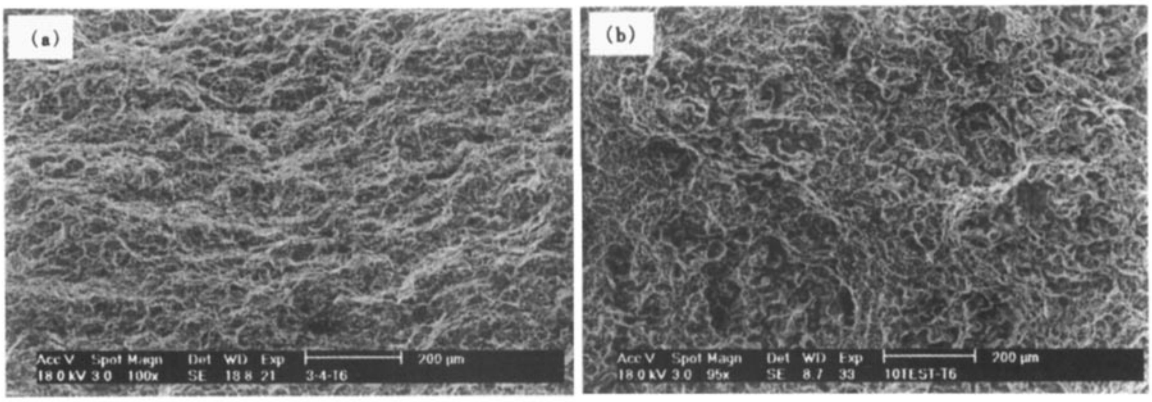


Fig. 3 Microstructure of the permanent mold cast tensile bar in the T5



(a)—squeeze-cast wheel; (b)—separately cast tensile bar

Fig. 4 Comparison of SEM fracture surface morphologies between squeeze-cast wheel and permanent mold cast tensile bar in the T6 heat-treating condition

5 CONCLUSIONS

1) Process parameters for squeeze cast of large load-bearing wheel were optimized. 40-45 MPa was chosen due to the limitation of the press machine used to produce a real size wheel with a projection area of 350 000 mm^2.

2) The mechanical properties of the T5 heat-treated squeeze-cast wheel are: τ_{UTS} 428 MPa, σ 360 MPa, elongation 13.1%, hardness distributed from HB120 to HB137.

3) The squeeze-cast wheels have a better mechanical property when compared with the gravity cast tensile bar. There is a 3%-5% increase in τ_{UTS} and 5%-9% increase in elongation. The squeeze-cast wheels have a better mechanical property when compared with the gravity cast one. The increase in elongation reached

24.8% and 20.2% in T5 and T6 heat-treating condition, respectively. Meanwhile, the increase in τ_{UTS} reached 8.1% and 8.6% in T5 and T6 heat-treating condition, respectively.

4) It is feasible to use squeeze cast method to replace forging method in large load-bearing wheel production.

REFERENCES

[1] Zehe R U. The squeeze play[J]. *Foundry Management & Technology*, 1999. 65-70.

[2] QI Pi-rang. *The squeeze casting*[M]. Beijing: The National Defense Press(in Chinese), 1984.

[3] Franklin J R and Das A A. Squeeze casting: A review of the status[J]. *The British Foundryman*, 1984, 77(3): 150-158.

[4] Gallerneault M, Durrant G and Cantor B. The squeeze casting of hypoeutectic binary Al-Cu[J]. *Metallurgical and Materials Transactions A—Physical Metallurgy and Materials Science*, 1996, 27(12): 4121-4132.

[5] LI Yuan-yuan, GUO Guo-wen, ZHANG Wei-wen, *et al*. Effects of alloying elements on hot tearing trends of Al-Cu alloy [J]. *The Chinese Journal of Nonferrous Metal*(in Chinese), 2001, 11(2): 791-795.

[6] LI Yuan-yuan and Ngai Tungwai Leo. Grain refinement and microstructural effects on mechanical and tribological behaviours of Ti and B modified aluminium bronze[J]. *Journal of Materials Science*, 1996, 31: 5333-5338.

[7] Morton J R and Barlow J. Squeeze casting-from a theory to profit and a future[J]. *Foundryman*, 1994, 87(1): 23-28.

[8] Doudoux J L, LeFloch C, Remy A, *et al*. Influence of filling speed and solidification pressure on macrosegregation in squeeze-casting[J]. *ALUMINIUM ALLOYS: THEIR PHYSICAL AND MECHANICAL PROPERTIES*, PTS 1-3, 1996, 217: 271-276.

[9] Lee Y W, Lin Y L and Yeh C H. Correlation of feeding and mechanical properties of A206 aluminum alloy plate casting [J]. *AFS Trans*, 1990. 935-941.

[10] Spada A T. Aluminum casters discuss porosity, melt quality [J]. *Modern Casting*, 1999. 58-60.

[11] Dong J X, Karnezis P A, Durrant G, *et al*. The effect of Sr and Fe additions on the microstructure and mechanical properties of a direct squeeze cast Al-7Si-0.3Mg alloy[J]. *Metallurgical and Materials Transactions A—Physical Metallurgy and Materials Science*, 1999, 30:(5): 1341-1356.

[12] Yue T M. Squeeze casting of high-strength aluminium wrought alloy AA7010[J]. *Journal of Materials Processing Technology*, 1997, 66(1-3): 179-185.

[13] Murali S, Trivedi A, Shamanna K S, *et al*. Effect of iron and combined iron and beryllium additions on the fracture toughness and microstructures of squeeze-cast Al-7Si-0.3Mg alloy[J]. *JOURNAL OF MATERIALS ENGINEERING AND PERFORMANCE*, 1996, 5(4): 462-468.

[14] Yang Y S and Tsao C Y A. Semi-solid squeeze-forming of A356 aluminium alloy with dendritic and non-dendritic structures[J]. *Int J of Materials and Product Technology*, 1998, 13(3-6): 334-346.