Rev. Adv. Mater. Sci. 33 (2013) 251-256

STUDY OF METAL FLOW OF TEE JOINT VALVE BODY BY MULTIDIRECTIONAL EXTRUSION DEFORMATION AND RECRYSTALLIZATION

Mei Cheng and Zhi Min Zhang

College of Materials Science and Engineering, North University of China, Taiyuan 030051, China

Received: October 17, 2011

Abstract. The effect of different deformation temperature, different deformation degree and different deformation rate on the recrystallized degree and grain size of copper tee joint valve body after Multidirectional extrusion deformation were Investigated. The results shows that the recrystallization structure is Homogeneous and fine (stick or needle shape) after Multidirectional active loading by half closed mould cavity at more than 720 °C and higher deformation rate (1~5 s^{-1}) when average deformation degree is above 50%. Through choose reasonable accurate processing routing, multidimensional active loading can make each deformation zone deformed simultaneously, which could significantly reduce the non-uniform deformation. Compared to the ordinary extrusion process, deformation dead zone obviously decreased and the microstructure of workpiece is more homogeneous and the deformation force is decreased greatly.

1. INTRODUCTION

Aluminum brass has good thermal conductivity, wear resistance, good corrosion resistance in the atmosphere and excellent machining performance. So the aluminum brass is widely applied for various valves which used in sea water, the oxygen, air, oil and other media [1]. But brass body by casting commonly support PN<2.5 MPa pressure, that much lower than steel body support and greatly limits the development and application. The strength and toughness of brass body by plastic forming has greatly improved [2-4].

As shown in Fig. 1, there are three internal cavities with not the same line to be formed while three-way valve forming. Using the traditional one-way extrusion forming technology need multi-pass complex process, so need high cost and product quality is not guaranteed.

The microstructure of the brass with 40% of zinc is composed of the (α + β) two phases at room temperature, and the brass is called the two-phase brass. The α solid solution has good low-temperature molding, and due to the solid solution strengthening effect of Zn it has high strength. But the brass is brittle at 300-720 °C, not suitable for processing in this temperature range [5-7]. The β is CuZn-based E-compound solid solution. The β has high plasticity performance at high temperatures, and improve the room temperature strength at low temperature. Therefore, (α + β) brass should be formed under the hot. When two-phase brass alloy hot forming, β phase at matrix body formed the hot deformation fibrous tissue. It can improve strength and wear resistant. Alpha phase of face-centered cubic lattice easy dynamic recrystallize. When processing above 700 °C, alpha phase can go through completely re-dissolution and recrystallization, Alpha phase analyses in beta phase at room temperature and in matrix deformation to form tiny needle structure makes material strength and toughness and as-cast structures have been greatly improved.

Corresponding author: Mei Cheng, e-mail: chengmei@nuc.edu.cn

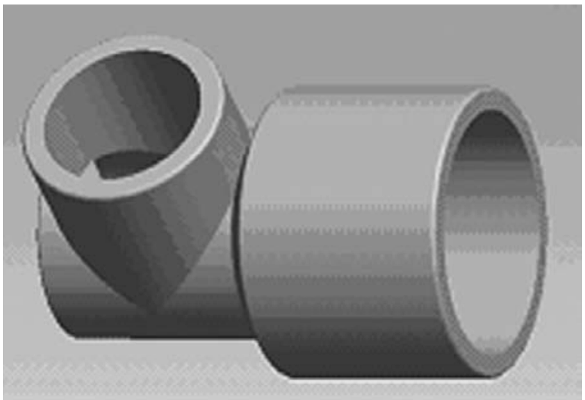

Fig. 1. Parts drawing.

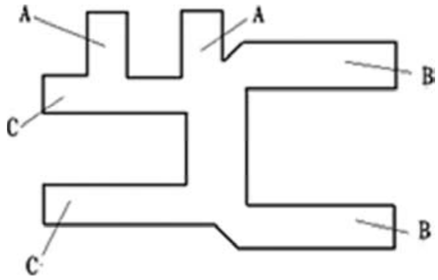

Fig. 2. Plane schematic diagrams.

In this paper, two-phase HAL60-1-1 brass billet is selected as body material, the crush test is carried on the new multi-extrusion machine, the direction of the punch is controlled to achieve a molding thin-walled cylindrical shaped links billet parts [8-10].

2. EXPERIMENTS

The Tee Joint Valve Body plane figure can be seen in Fig. 2. Parts external dimensions 145x120x100, extrusion finished weight of about 20 kg; the wall thickness of *A*, *B*, *C* three-part were 18, 18, and 25 mm, deformation 77%, 69%, 64% respectively, $\Phi 100 \times 150$ mm cylindrical bar is used.

The test including two parts:

(1) Nonlinear simulation software surperform-3D software is used to simulate the forming process , a reasonable load parameters are determined by the process.

(2) According to the simulation results of extrusion process from test and analysis of microstructures extrusion parts, the forming process parameters on the microstructure were investigated.

Table 1. Load parameters.

Temperature (°C)	Loading order	Loading speed (mm/s)
720	Simultaneously	1
750	In turn	5

2.1. Simulation of metal flow of tee joint valve body by multidirectional extrusion deformation

Orthogonal experiment is used in the simulation, temperature, loading sequence and loading rate are taken into account, considering two levels of each factor as shown in Table 1, alloy HAL60-1-1 is used in the simulation, components is shown as Table 2, material is assumed as steel molding materials, selected extrusion temperature of 720 and 750 °C, formed under isothermal temperature [11,12].

The equivalent coefficient of Al to Zn is 6%, an increase in β, zinc equivalent is calculated as follows. The Al element is equal to increase the equivalent of Zn, make beta area increased, and zinc equivalent calculation formula as follows:

$$X_{Zn} = \frac{C_{Zn} + \sum C \cdot \eta}{C_{Zn} + C_{Cu} + \sum C \cdot \eta} \times 100\%.$$

Among them the C_{Zn} and C_{Cu} are the contents of copper and zinc respectively, the *C* is the content of other alloy elements. Take them into the formula and get the result:

$$X_{Zn} = 43.9\%. \quad (2)$$

Fig. 3 shows schematic diagram of metal flow when loading simultaneously and loading in turn respectively, (a) is loaded intermediate state, (b) is the end of the state, from the simulation results, while loading simultaneously, the metal flow scattered, filling uneven, resulting in left part of A area is not filled fully. Therefore, this loading process is unreasonable.

Table 2. The alloy component of HAL60-1-1.

Group	Code name	Main chemical composition (wt. %)		
		Copper	Zinc	Other alloying element
Aluminium brass	HAl60-1-1	58.0-61.0	Margin	Al0.7-1.5,As 0.1-0.6,Fe0.7-1.50.7-1.5

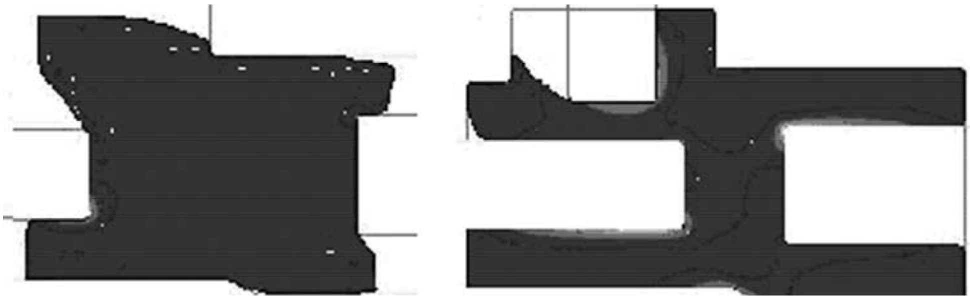

Fig. 3. Metal flow simulation.

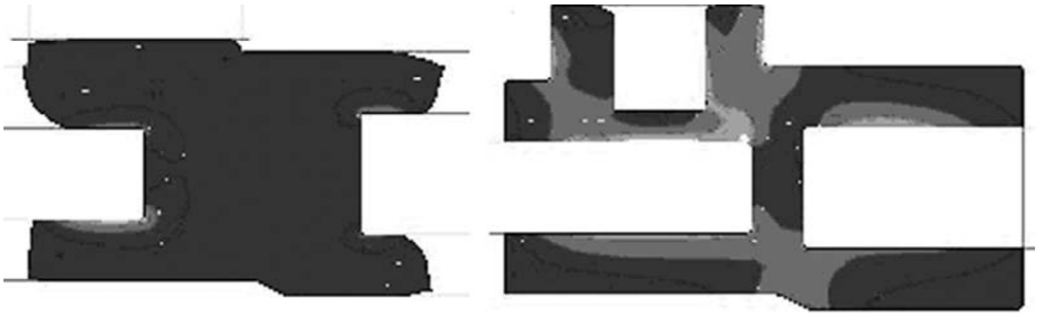

Fig. 4. Metal flow simulation.

Fig. 4 shows the initial stage of deformation of the loading process, A area is not filled, firstly, dynamic model by the relative motion of two molds to achieve the level of backward extrusion forming two holes. The flowing rate of the metal is relatively uniform, every parts is filled by the fluid at a uniform rate, at the late movement stage of dynamic model, the vertical dynamic model start moving, Liquid metal flow reversely through the bottom of A area, which filling A area, a complete part can be obtained by this program.

The simulation result indicates that taking steps to load is a reasonable process for the multidirectional extrusion deformation machine.

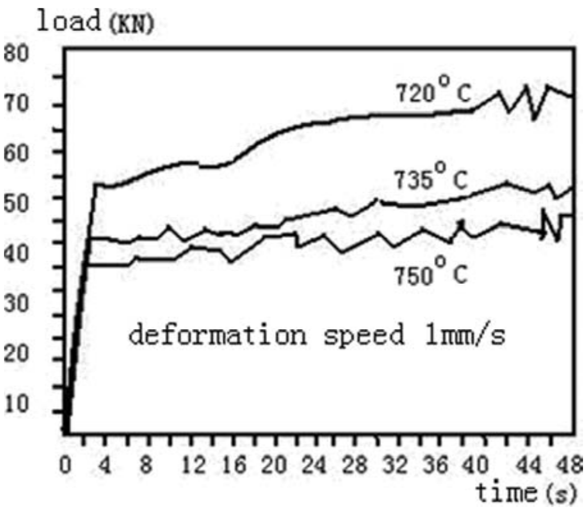

Fig. 5. Punch 2 load route graph.

Simulation result shows that the loading speed and loading temperature only affects metal stress in the deformation, while the fluid of the metal and strain is a very small factor, so from the filling and reasonable consideration, these two factors can be ignored. The loading order determines the metal flow.

2.2. Tee joint valve body extrusion experiment and microstructure observation

Tee joint valve body extrusion experiment is carried on the multi-isothermal extrusion hydraulic machine, according to the results above, in order to load test the way, the load is taken in turn, the temperature of the material is 720, 735, and 750 °C, respectively; the loading speed is 1, 3, and 5 mm/s.

Tee joint valve body extrusion experiment is carried in the sequent solidification way, the metal flows stably and uniformly with a good formability. But the billet temperature and loading rate, Fig. 6 shows the deformation rate at 1 mm/s forming the hole B, the measured load stroke curve can be seen from Fig. 5, according to the simultaneously loading process, the punch 2 is started in the second step, in the initial stage, The force upon the load punch increases to a certain value rapidly, it is the stable deformation stage, this time punch loading rise slowly as the deformation increases. Integration of the different test results under the conditions of deformation can be drawn as follows. Deformation temperature is higher, the faster extrusion speed,

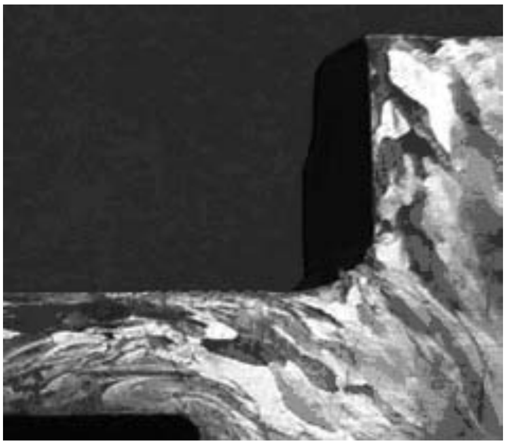

Fig. 6. Macro-structure of workpiece.

Fig. 7. Micro- structure of blank.

the deformation of the load by the smaller punch. Which influenced the temperature, the deforming force of the alloy in the 720 °C is higher than that in 735 and 750 °C, and as the deformation increases, the load rate increases.

Samples of macro-structure and micro-structure are observed under different conditions. Preparation of macro-structure style level in the tube wall piece is to take a larger part of the deformation of a typical position, as shown in Fig. 6, we mill the face and grind the sandpaper, after it is corroded in the 30% nitric acid for 2 minutes, then it is watered, the grains can be clearly observed in the 5 to 10 times magnifying glass. Preparation of microstructure subject need to be grinded by the sandpaper, it is polished by the alumina suspension and then should be corrosed (etching solution composition: concentrated hydrochloric acid and concentrated nitric acid by 3:1 mixture) for 1 minute, then it is observed under the microscope after it is washed by clean water.

3. THE MACRO-STRUCTURE ANALYSIS

The grain size of the copper alloy billets is large, it can be seen in the 5 times magnifying glass. By five times the structure chart can be seen copper alloy, the average grain size of the alloy is 1-2 mm, which is in a irregular distribution, Fig. 6 is the macro-items structure chart. The structure of the workpiece material deformation different as the manifestations is in different structures, firstly, the flow lines can be seen clearly as the alloy is squeezed between 720 and 750 °C. The structures have not been fully recrystallized, the metal flow along the direction of the phenomenon shows a strong texture, the process flow line can be clearly visible.

According to the phase diagram, 43.9% zinc content can be seen, it is the β single-phase region when the actual temperature rises to 720 °C, solid-state phase transition happens when it is heated above this temperature, α phase transforms to β phase. High temperature β phase has a high molding quality, it is easy to be formed, so the transformation of the alloy above 720 °C is a single transformation of β-phase, α phase is the electronic compound which is CuZn-based body with body-centered cubic lattice, at the 720-750 °C range, recrystallization do not happen, but the precipitation is associated with the formation of α-phase flow line structure.

4. ANALYSIS OF MICROSTRUCTURE FORMATION

The microscope microstructure can be seen that the second phase is in distribution of a large multi-spindle with sharp corners and the second phase and matrix boundary is smooth, as is shown in Fig. 7, H60-1-1 alloy is β phase matrix, α-phase is the second phase which is distributes in the matrix, Dendritic α phase is clearly visible. As the α-phase non-brittle and hard phase, although there were large needle and the matrix will not destroy the continuity of the matrix, therefore, the plastic quality will not be reduced and this shape is also beneficial to maintaining the strength of the matrix.

In the HAL60-1-1 alloy microstructure changes, there are mainly a-phase recrystallization, with different processing conditions, a-phase were precipitated in two different ways, as is shown in Fig. 8, there are parts formed at (a) 720 °C and (b) 750 °C temperature respectively, samples can be extracted from the same part of the microstructure at 720 °C under the process, as the mold cools, the temperature drops to 720 °C immediately, β-phase solid solution reaches saturation, it starts to decompose α phase precipitates. As deformation proceed, finally, α-phase distributes along β phase,

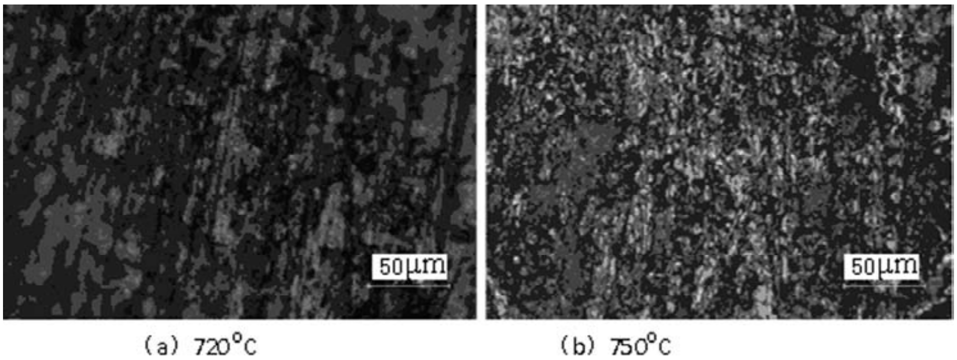

Fig. 8. Micro- structure of workpiece.

showing relatively large bulk line distribution. From the relationship between the deformation temperature and the microstructure effects, it can be seen that the slower the deformation, the more obvious the α-phase distribution this block is caused by two factors, firstly, as the deformation becomes slowly, the process becomes longer, the processing time in the precipitation of a phase is full. Secondly, at the two-phase temperature range, deformation is conducive to the precipitation of α phase, as the deformation increase, α-phase can precipitate in all parts of the matrix and have sufficient time to grow up. (b) is a structure formed under higher temperature, due to the high processing temperature, α-phase precipitate lately, sometimes it occurs after the deformation, then the rod shape α-phase precipitates, but it is different from the original structure obviously.

(1) the length of rod structure and the direction of metal are equal.

(2) the interface of the two-phase shows a uneven shape, there are washboard-like slips in many places in the surface of α phase with the processing direction of the line 45 °C.

At room temperature, this structure can improve the strength of the workpiece, so in the hot deformation, if to obtain high-strength materials, isothermal deformation should be used, the deformation temperature should be controlled over 720 °C, to avoid appearance large granular of a phase.

5. HAL60-1-1 DURING HOT DEFORMATION MICROSTRUCTURE MODEL

HAL60-1-1 alloy is analyzed after when the deformation happens, the macrostructure and microstructure texture shows that the alloy in the thermal processing of dynamic recrystallization is done while the soften process happens, α and β phase do not changes at the same time but the recrystallization grain degree is changed, no recrystallization happens as the matrix β phase in the 720-750 °C range deforming, so the original billet grain recrystallization process is not only in the processing of metal flow along the direction of rotation and the grains were elongated to form thermal texture, the structure chart above shows that β-phase thermal deformation of fibrous tissue increases as deformation increases. During hot deformation in the matrix structure, distribution of α phase, as a high temperature transformation of β phase, and then re-crystal precipitation in the low-temperature process, therefore, under different deformation conditions, the shape and distribution different greatly.

HAL60-1-1 alloy deformed at 720-750 °C range, the thermal deformation texture is β-phase + α-phase recrystallized. If the thermal deformation temperature is always above 720 °C, α phase does not appear, when the deformation finishes, the temperature fell below 720 °C, α-phase starts to precipitate, this time as β phase is the supersaturated thermal texture structure, its crystal lattice distortion and dislocation accumulation of a certain direction are present, α-phase is the texture direction and therefore the texture is rod-like or needle-like structure. If the temperature is below 720 °C, then saturated β phase will be precipitated in α phase, at this time β phase texture do not precipitate α phase texture, which is plate-like.

The forming properties of two-phase brass alloy depends on the performance of β phase, because the heat processing of two-phase brass, generally is at a temperature range of β-phase, β phase is the CuZn-based compound ,which is body-centered cubic lattice, it has good high temperature plastic quality, the reason of the hardening phenomenon is mainly because of β-phase lattice distortion, the softening process is because deformation increases and temperature drops, face-centered cubic lattice of α-phase is precipitated. While α-phase re-precipitates, two-phase brass recrystallizates, the deformation of two-phase brass is to keep the workpiece fibrous matrix, the matrix α phase re-melted and recrystallizated. Although the α-phase is face-centered cubic lattice with low intensity, good plasticity, it is saturated of full dissolution of zinc, the lattice distorted, so α phase has a high intensity, while rod-like or needle like α phase and β phase interface is long, the fusion quality is better than the plate-like, the material strength and toughness can be improved.

6. CONCLUSION

(1) The number simulation provides a better way for tee joint valve body that is in multidirectional extrusion deformation when it is loaded, flow direction will be assigned, a shape with different angles, special section tube parts within the hole. Tee joint valve body extrusion experiment is carried, material HAL60-1-1 brass is selected, in a certain range, as the appropriate deformation temperature and strain rate increase, it can reduce the deformation resistance

(2) HAL60-1-1 large grain size copper alloy is selected to produce tee joint valve body extrusion experiment, the reasonable temperature is 720-750 °C, after deformation β-phase thermal is fibrous tissue, within the basement of β phase fibrous tissue, according to different the deformation conditions, α-phase shows irregular block or rod distributions. When the heat distortion temperature is below 720 °C, deformation occurs a the situation precipitated α phase, the first precipitation of α phase in the subsequent deformation process, there are significant internal lattice distortions and stacking faults, resulting in the formation of massive recrystallization structure.

(3) Because irregular rod-like α phase structures can help to improve the mechanical properties, when the processing temperature is between 720 and 750 °C, the higher the temperature is, the more rod like texture.

REFERENCE

[1] Yang Hong Liang, Kang Da Chang and Zhang Zhi Liang // *Valve* **1** (2001) 13.
[2] Yang Hong-Liang, Kang Da-Chang and Zhang Zhi-Liang // *Die and Mould Technology* **3** (2001) 9.
[3] Tan Shu Song, *Nonferrous Metal Material Science* (The Metallurgical Industry Press, Beijing, 1991).
[4] Sun Hongyi, Kang Dachang and Chen Yu // *Forging &Stamping Technology* **3** (2001) 6.
[5] Yung-Fu Hsu, Wen-Hsing Wang and C.M. Wanyman // *Metallurgical Transactions A* **22A** (1991) 1473.
[6] S.V. Raj // *Journal of Materials Science* **24** (1989) 3196.
[7] Zhang Hui, Zhang Hong *et al*. // *Nonferrous Met. Soc. China* **16** (2006) 562.
[8] Yang Wang, Yuanxin Zhou and Yuanming Xia // *Materials Science and Engineering A* **372** (2004) 186.
[9] Li Wen Bing, Tang Sheng Yu, Yan Jing, Zhao Zhen and Shen Bao luo // *Hot Working Technology* **35** (2006) 40.
[10] F. Stachowicz // *Jourrnal of Materials Processing Technology* **100** (2000) 230.
[11] N.C. Tang // *International Journal of Pressure Vessels and Piping* **77** (2000) 751.
[12] A. Gontarz // *Journal of Materials Processing Technology* **177** (2006) 228.