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ARTICLE

Microstructures and Mechanical Properties of Al-12Zn-2.4Mg-1.2Cu Alloy under Different Deformation Ways

Chen Gang[1,2], Chen Wei[2], Zhang Guowei[2], Zheng Shunqi[2], Zhang Zhimin[1]

[1] North University of China, Taiyuan 030051, China; *[2] Ningbo Branch of Ordance Science Institute of China, Ningbo 315103, China*

Abstract: Al-12Zn-2.4Mg-1.2Cu (wt%) alloy billets as-deposited were extruded to be *Φ*100 mm bar, *Φ*100 mm×*Φ* 80 mm seamless pipe and 160 mm×15 mm stripper plate under different deformation ways. The microstructures of the products as-heat-treated were studied by optical metallographic and scanning electron microscope, and the mechanical properties were also measured. Metallographic microstructures show that the grains in the initial billets are almost equiaxed with diameter about 20 μm. There are some second phases precipitated distributing in the grains and on the grain boundary. The deposited ventages around the grains as-deposited were welded together by a welding metallurgy way during extrusion process. The flow lines were clearly observed in the extrusion direction in all different extruded products. For the products as-heat-treated, the tensile strengths, the yield strengths and the elongations of the bars are 688 MPa, 654 MPa and 12% in the cross direction (CD), while 698 MPa, 674 MPa and 10.5% in the longitude direction (LD); for the plates they are 783 MPa, 748 MPa and 7% in CD; while 751MPa, 719 MPa, and 8% in LD; for the pipes they are 781 MPa, 735 MPa and 9% in LD. Scanning electron microscope examination reveals the fracture characteristics of the fractured specimens exhibit three different fracture models which are ductile fracture, mixed fracture and brittle fracture corresponding to bars, pipes and plates, respectively.

Key words: Al-12Zn-2.4Mg-1.2Cu alloy; mechanical property; microstructure; deformation way; fracture morphology

Aluminum alloys have primary potential for lightweight structural application in automotive and aerospace industries[1]. The 7000 series aluminum alloys are one of the most important structure materials. On account of their specific strength, stiffness and primary potential for lightweight structure applications, they have been used in aviation, spaceflight and other fields [2-4]. With the development of ordnance, aviation et al, higher strength, stiffness and other properties[5-7] are required.

In order to meet the applications, many unconventional methods are used to manufacture 7000 series aluminum alloys. Because of advantages of solid solubility extending and rapid cooling, spray forming process is one of the classical methods to manufacture the super strength aluminum alloys. However, according to the principle of spray forming process, the deposited billets must be extruded into bars, seamless pipe or stripper plates for structure parts post deformation.

Although many study works on the mechanical properties and microstructure of the 7000 series aluminum alloys manufactured by spray forming process[8-12], little attention is paid to the Al-12Zn-2.4Mg-1.2Cu (wt%) aluminum alloy. In the present work, the mechanical properties and microstructures of Al-12Zn-2.4Mg-1.2Cu aluminum alloys were systematically investigated in order to understand the influence of deformation ways on them for the experimental alloy extruded products such as extrusion bars, seamless pipes and stripper plates.

1 Experiment

The experimental alloy billets as-deposited were fabricated by spray forming process on the OS10 spray forming equipment manufactured by Osprey company UK. The major elements excluding Al contents were 12 Zn, 2.4 Mg, 1.2 Cu, 0.3 Zr, and 0.05 Ni (wt%). There were three different

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Corresponding author: Chen Gang, Candidate for Ph. D., College of Materials Science and Engineering, North University of China, Taiyuan 030051, P. R. China, Tel: 0086-574-87918483, E-mail: cg661231@163.com

deformation ways as following. The Φ280 mm ×500 mm billets as-deposited were extruded into Φ100 mm bars and Φ100 mm × Φ80 mm seamless pipes at 390 ℃ on 3200UTS horizontal double-action backward extrusion presses. And 160 mm×15 mm stripper plates were fabricated by the same size billets at 390 ℃ on 5000 t horizontal extrusion presses. The billets as-deposited and different extrusion products are shown in Fig.1.

All the properties and microstructure mentioned in this paper are as-heat-treated. All tests under different deformation ways followed the hot treatment principle. The solution treatment was firstly performed at 450 ℃ for 1.5 h, and then the solution temperature was elevated to 480 ℃ for 2 h in salt bath. The aging treatment was firstly carried out at 130 ℃ for 13 h, and then the aging temperature was elevated to 160 ℃ for 4 h in the muffle. Lastly, the specimens were taken out from the muffle followed by air-cooling to room temperature.

The tensile test specimens were machined according to ASTM E8 (2008), and tested on the CMT-4105 testing machine with a constant crossed speed of 2 mm/min at room temperature. The microstructures were observed on the Laika MEF4 optical microscopy (OM) and QUANTA FEG 250 scanning electron microscope (SEM). The specimens were electro-polished and anodized in Kller reagent (2 mL HF + 3 mL HCl + 5 mL HNO_3 + 190 mL H_2O).

2 Results and Discussion

The fine-grain ingots can be fabricated by the spray forming process. Fig.2a shows the grains in the billet as-deposited are mostly equiaxed. And the average diameter is about 20 μm. A plurality of second phase precipitates distribute in the grains and the grain boundary in the continuous process of rapid cooling, which can be also viewed in Fig.2a. At the beginning of the spray forming, the melt is atomized into droplets and semi-solid droplets which are supersaturated solid solutions. And then the droplets and semi-solid droplets grow up to be jet under the atomization-cooling common effects of the gas flow at the meantime. Droplets and semi-solid droplets in the jet fill in the ventages after spreading out and striking each other during the depositing process of droplets on the sediment pan. That is reason for equiaxed grains forming and many second phases precipitating in the deposition ingot.

According to the droplets and semi-solid droplets stacking principle, some ventages are formed inevitably distributing around the grain in the billets as-deposited which can be seen in Fig.2a. However, those deposited ventages are welded together after hot extrusion as shown in Fig.2b~2f. That is why it is rare to manufacture structure parts using billet as-deposited. Conversely, some different plastic forming deformation processes are used to prepare products with different shapes and sizes for subsequent further deformation.

Fig.2c~2e show the longitudinal section microstructures of the extrusion bar, and the stripper plate, respectively. Those microstructures contain many fibrous deformed structures. And the grains distribute along the extrusion direction. Hence, the flow lines as an obvious feature of extrusion metal are shown in the three images. During the extrusion process, some

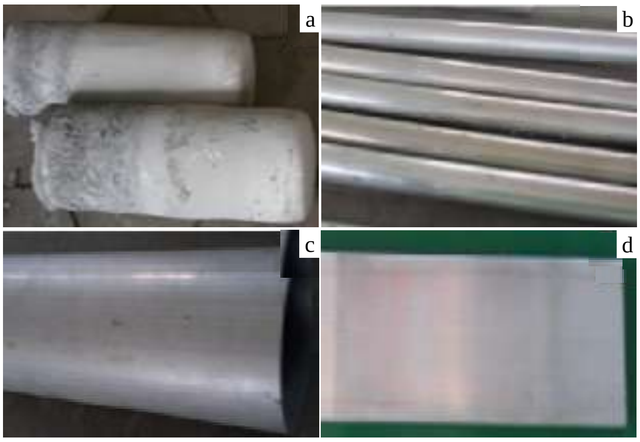

Fig.1 Billets and extrusion products: (a) billets as-deposited, (b) bar, (c) seamless pipe, and (d) stripper plate

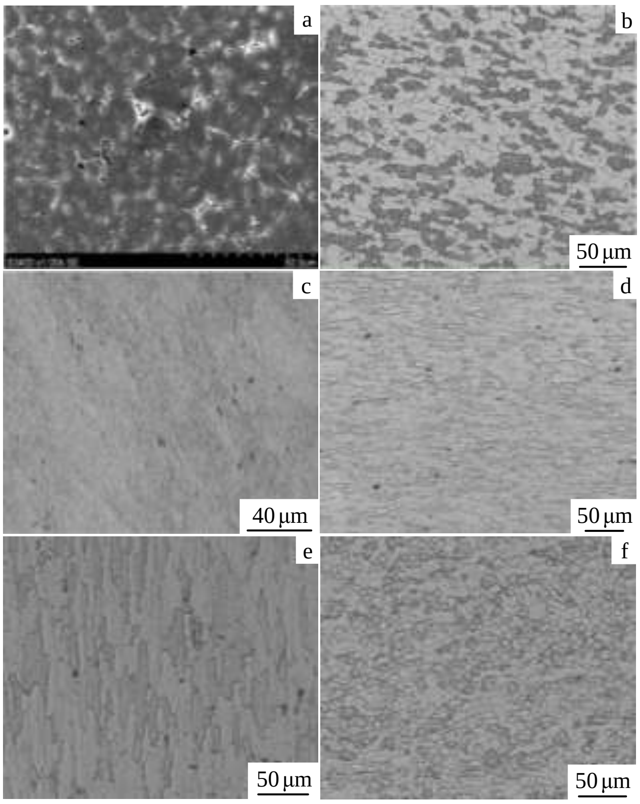

Fig.2 Microstructures of extrusion products: (a) billets as-deposited, (b) extrusion bar cross section, (c) extrusion bar longitudinal section, (d) seamless pipe longitudinal section, (e) stripper plate longitudinal section, and (f) stripper plate cross section

grains as-deposited are elongated and some are elongated to be new smaller grains distributed in the longitudinal direction (LD). As a result, for the extrusion stream lines are observed in Fig.2c~2e. The smallest grain size is illustrated in Fig.2c. The average grain size is about 8 μm. The secondly uniform is seamless pipes with about 30 μm in average grain size in Fig.2d. The coarsest grain size of about 80 μm is given in the longitudinal section of stripper plates in Fig.2e.

Fig.2b and 2f show the cross section microstructures of extrusion bars and stripper plates. The obvious recrystallization phenomenon occurs inadequately as shown in the two images. The microstructures in the cross section are typical mixed grain structures including recrystallized microstructure and deformed microstructure. There are many smaller grains distributed in local areas and many anisometric grains distributed in the most regions. The phenomenon mentioned above is owing to the unevenly distributed distortion energy as recrystallization driving force. During the forming process of products with different cross-sectional shapes, the metal flowing characters corresponding to distortion energy are also different. During the hot treatment process, the more sufficiently recrystallization occurs, the higher distortion energy is in some local areas. Therefore, the distortion energy is also unevenly distributed in the seamless pipes and stripper plates, leading to larger grains during the hot treatment. So, the remarkable local irregularity of the larger grain can be observed in the longitudinal direction (LD) in Fig.2d and 2e.

The grain sizes of extrusion products are smaller and more uneven than those of billets as-deposited. There are two main reasons are following. Firstly, the grains as-deposited are elongated, cracked and spread out in the extrusion direction during the plastic deformation. So, many smaller grains in cross section can be seen in Fig.2b and 2f. Secondly, recrystallization occurs in the process of hot treatment and the size of many new grains become larger in the LD which can be seen in Fig.2c and 2e.

Fig.3 shows the mechanical properties of products under different deformation ways. The average tensile strength and yield strength of extrusion bars are 698, 674 and 688, 654 MPa in the LD and CD, respectively. There are few significant differences in yield strength and tensile strength in the different directions. The strength value is well corresponding to the variance of grain size. The main reason for few significant differences is the squeeze effect mentioned above which can be seen in Fig.2b. As stripper plates of experimental alloy, the tensile strength and the yield strength are 751, 719 and 783, 748 MPa given in the LD and CD. Comparing with the strengths in the CD and LD, the strength in the CD are higher by about 4.3% and 4.0%, respectively. The strength difference of the plates can be explained using comparative analysis of organizational characteristics in Fig.2e and 2f. The tensile strength and yield strength of seamless pipes is 781 and 735 MPa, respectively.

The different extrusion ratios for the bar, the seamless pipe and the plate are 7.84, 21.8 and 8.17, respectively. According to the strength test results, there is no sufficient evidence to illustrate the relationship between strength and extrusion ratios. However, it can be concluded that tendency of the strength increases is the same as other alloys with the extrusion ratio increasing.

The elongation of different directions extrusion products is illustrated in Fig.3c. the elongation of the bars is 10.5% (LD) and 12% (CD), and that of the stripper plates is 8% (LD) and 7% (CD). And the value of the seamless pipe is 9% (LD). In order to find the reasons for the different elongation values of the experimental alloy under different deformation ways, the tensile fracture surfaces of different products were observed by SEM and the results are shown in Fig.4.

The fracture surface shows many fine dimples for the extrusion bar which can be observed in Fig.4a. The mean size of those dimples is less than 5 μm. The significant characteristic

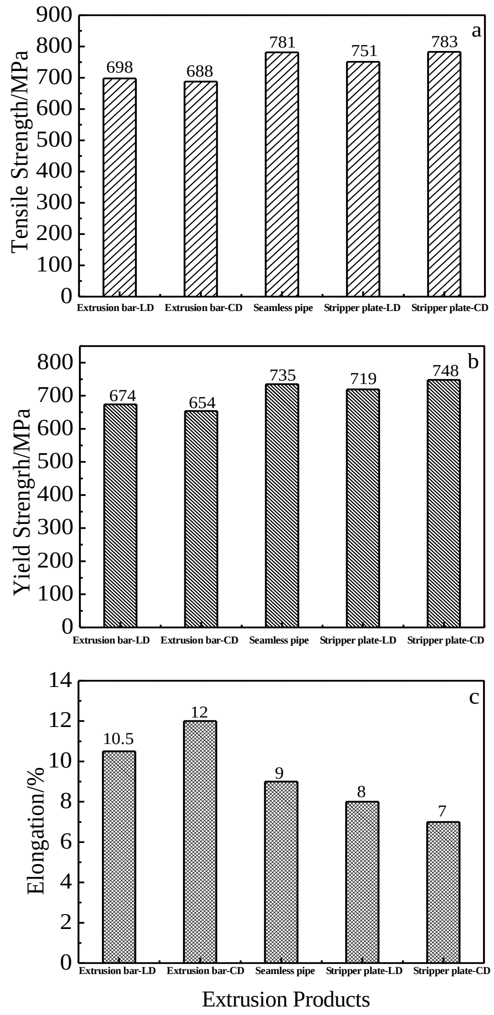

Fig.3 Mechanical properties in CD and LD of the different products: (a) tensile strength, (b) yield strength, and (c) elongation

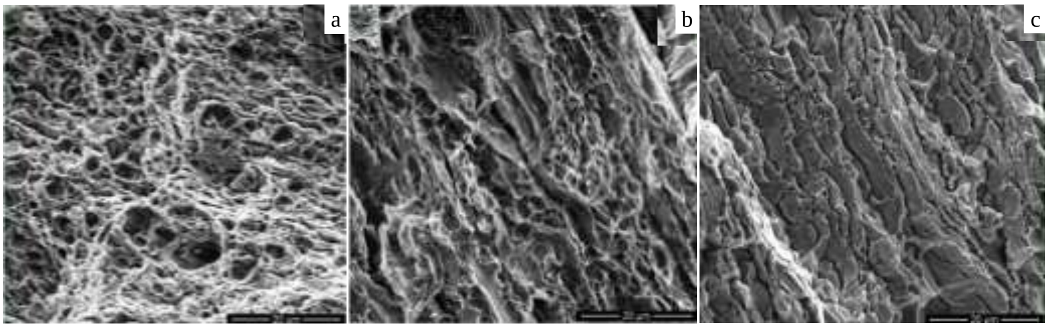

Fig.4 Fracture morphologies of extrusion bar (a), seamless pipe (b), and stripper plate (c)

of ductile fracture can be also seen in Fig.4a. Therefore, the tensile fracture mechanism of the bar is ductile fracture. The larger and more uniform the size of dimples are, the better ductility is [13,14]. In Fig.4b, little dimples and some strip tearing ridges can be observed on the fracture surface of the seamless pipe. The fracture mechanism is mixed fracture along and through the grain boundaries. Fig.4c shows that the fracture surface is characterized by a combination of most intergranular brittle regions and a few cleavage regions. There are many smaller precipitations which can be observed clearly on grain boundaries.

3 Conclusions

1) The grains in the initial billets as-deposited are mostly equiaxed grain with diameter about 20 μm. A plurality of second phases precipitate distributing in the grains and the grain boundary. The deposited ventages are welded together after different deformation ways. Some grains as-deposited are elongated and some are elongated to be new smaller grains distributed in the longitudinal direction under different deformation ways. The flow lines are observed in microstructures of extrusion bars and stripper plates in the extrusion direction.

2) The mechanical properties of different deformation products are all excellent. Taking the bars and plates for example, there are the least significant distinction between tensile strength and yield strength of different deformation products in the same direction. The tensile strength, yield strength and elongation of the bar in the cross section are 688 MPa, 654 MPa and 12%, respectively. And the higher performance values of the bar are in the extrusion direction. Contrary to the bar, the higher properties of the plate are in the cross section which are 783 MPa, 748 MPa and 7%, respectively.

3) Many fine dimples are on the fracture surfaces of the extrusion bar. Little dimples and some strip tearing ridges can be observed on the fracture surface of the seamless pipe. Most intergranular brittle regions, a few cleavage regions and some finer precipitations are displayed on grain boundaries on the fracture surfaces of the stripper plates. The fracture characteristics of the fractured specimens reveal three different fracture models which are ductile fracture, mixed fracture and brittle fracture corresponding to the bars, the pipes and the plates, respectively.

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不同变形方式下 Al-12Zn-2.4Mg-1.2Cu 合金的微观组织与力学性能研究

陈　刚[1,2]，陈　伟[2]，章国伟[2]，郑顺奇[2], 张治民[1]
(1. 中北大学，山西 太原 030051)
(2. 中国兵器科学研究院宁波分院，浙江 宁波 315103)

摘　要：由喷射沉积制备 Al-12Zn-2.4Mg-1.2Cu (质量分数，%)合金的沉积锭，以不同挤压变形方式制备成 *Φ*100 mm 棒材、*Φ*100 mm×*Φ*80 mm 无缝管材以及 160 mm×15 mm 的板材。通过光学显微镜、扫描电镜以及力学性能试验研究了不同挤压制品热处理态的组织和力学性能。沉积态合金的显微组织中，晶粒为等轴晶，大小约 20 μm。在挤压变形过程中，以冶金焊合的方式消除了原先分布在沉积态中晶粒周围的沉积孔隙。不同挤压制品的挤压方向上，金属流线清晰可见。挤压制品的抗拉强度，屈服强度及延伸率测试结果表明：热处理后的棒材横向分别为 688 MPa、654 MPa 和 12%，纵向分别为 698 MPa、674 MPa 和 10.5%；热处理后的板材横截向分别为 783 MPa、748 MPa 和 7%，纵向分别为 751 MPa、719 MPa 和 8%；热处理无缝管材的纵向分别为 781 MPa、735 MPa 和 9%。拉伸断口显示，板材、无缝管材以及挤压板材对应的断口分别呈现出韧性断裂、混合型断裂以及脆性断裂形貌特征。

关键词：Al-12Zn-2.4Mg-1.2Cu 合金；变形方式；微观组织；力学性能；断口形貌

作者简介：陈　刚，男，1982 年生，博士生，中北大学材料科学与工程学院，山西 太原 030051，电话：0574-87918483，E-mail: cg661231@163.com