Hydrostatic Extrusion Experiment on AZ80 Magnesium Alloy Tube-Expanding Forming under Ultra-High Pressure

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Abstract. A series of systematic experiments were completed on self-developed ultra-high pressure hydrostatic extrusion equipment to determine the effects of key process parameters on AZ80 magnesium alloy tube-expanding forming. Compared with other parameters, extrusion ration has a significant impact on maximum extrusion pressure and unloading pressure. Through material performance tests, highest average tensile ultimate strength (380.0Mpa) and average tensile yield strength (369.3Mpa) was obtained at homogenization temperature of billet 400 ℃, homogenization time of billet 32h, preheating temperature of extrusion cylinder 180 ℃, extrusion ratio 2.77 and angle of core die 120 °, accompanied by elongation percentage 7%. In the condition of experiment NO.13 (homogenization temperature of billet 400 ℃, homogenization time of billet 16h, preheating temperature of extrusion cylinder 220 ℃, extrusion ratio 1.25 and angle of core die 120 °), tensile strength, yield strength and elongation percentage achieved a balanced combination with relative low extrusion pressure. Metallographic test also indicates that the ductility of expanding forming tube still has improving potential by annealing recrystallization or other post-treatment processes which is effective to completely eliminate the bulk grain.

1. Introduction

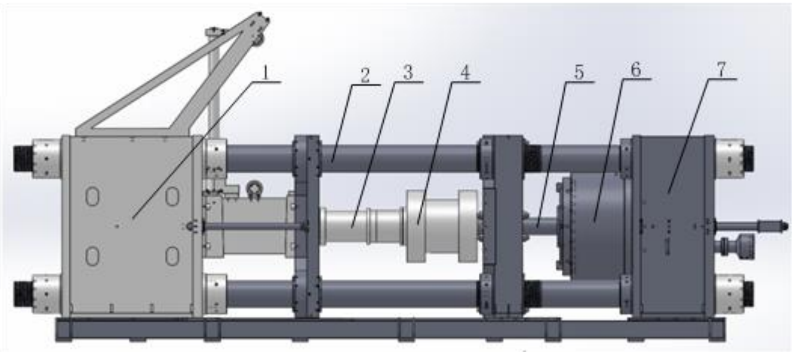
Magnesium alloy has received much attention in recent years due to its strong potential as lightweight and energy-saving material in structural applications [1]. Now most of the magnesium alloy parts are made by the traditional casting process with its strength relatively low. Various processes have been employed to promote its mechanical properties, which include rolling, hot forging and conventional extrusion and hydrostatic extrusion [2]. Hydrostatic extrusion is a novel process for forming hardly-deformed materials like magnesium [3]. In hydrostatic state, magnesium alloy shapes smoothly with relatively low temperature during the extrusion process. This forming method enables higher extrusion ratio at lower extrusion temperatures than commercial direct and indirect extrusion. An extremely fine-grained microstructure, excellent ductility and enhanced yield strength of the magnesium alloys were received by this extrusion method [4]. Typical processing temperatures for direct or indirect extrusion of magnesium alloys are in a range of 260–450 ℃ [5]. The behavior of magnesium alloy during hydrostatic extrusion was investigated that this process offers the possibility to decrease the extrusion temperature to 100 ℃ for AZ31, AZ61, ZM21, ZK30, ZE10 and 110 ℃ for AZ80 [4].

The high performance magnesium alloy tubes prepared by the hydrostatic extrusion process have huge advantage in the military field, aerospace industry and related industries [6]. However, hydrostatic extrusion technology of high performance and large diameter magnesium alloy tubes is not widely used because of uncertainty process parameters. Especially for ultra-high pressure hydrostatic extrusion, systematic research on process parameters is not enough now.

The hydrostatic extrusion process parameters have a strong influence on the workability, the microstructure evolution and the mechanical properties of magnesium alloys [7-8]. Some crucial process parameters of tube hydrostatic extrusion like preheating temperature and die angle were studied in former researches [9-10]. To optimize the process parameters for batch production, based on a great quantity of small-scale model experiments and numerical simulations, a series of systematic tube-expanding extrusion experiment and material tests were carried out on the self-developed 4000t ultra-high pressure hydrostatic extrusion equipment.

2. Experiment

Figure 1 shows the structure of horizontal hydrostatic extrusion equipment, mainly containing front beam, tension columns, extrusion die, extrusion cylinder, extrusion shaft, master hydraulic cylinder and back beam. Extrusion cylinder is filled with extrusion medium and its internal pressure capacity is up to 600MPa. The billet is under the pressure of high-pressure medium. Castor oil is employed as extrusion medium which was proved effectively in former experiments. Powered by hydraulic pump station, the master hydraulic cylinder is in a low-pressure state. At beginning, the extrusion shaft is pushed by master hydraulic cylinder and the castor oil in extrusion cylinder is compressed as extrusion shaft moving forward which transform its state to ultrahigh–pressure. As castor oil boosting, the billet flows in the die cavity forming the tube when castor oil's pressure is high enough to overcome the total deforming resistance and the contact friction between the material and the inner wall of die. There has a fully sealed connection between extrusion shaft and extrusion cylinder to guarantee ultra-high pressure during tube-expanding forming. A special die, shown in Figure 2, was designed to realize magnesium alloy tube-expending process.



1-front beam; 2-tension columns; 3-extrusion die; 4-extrusion cylinder; 5-extrusion shaft; 6-master hydraulic cylinder; 7-back beam

Figure 1. The horizontal hydrostatic extrusion equipment.

Orthogonal design was imported to determine the experiment scheme, ensuring equilibrium comparability. The key process parameters have been choosed based on our small-scale model experiments and numerical simulation, consisting of homogenization temperature of billet (HTB, ℃), homogenization time of billet (HT, h), preheating temperature of extrusion cylinder (PTC, ℃), extrusion ratio (ER) and angle of core die (ACD, °). For better forming, the preheating temperature of billet is set as 290 ℃. Specific experiment scheme is shown as Table 1. The specimen after tube-expanding forming is in Figure 3, with high surface quality both in inner wall and outer wall.

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Table 1. AZ80 magnesium alloy tube-expanding forming experiment scheme.

Number	HTB/ ℃	HT/ h	PTC/ ℃	ER	ACD/ °	σ_s/MPa	σ_b/MPa	δ/%	MP/MPa	UP/MPa
NO.1	380	16	180	1.25	105	345.4	376.4	8.6	302	200
NO.2	380	24	220	1.92	120	276	280.7	3.2	503	360
NO.3	380	32	220	2.77	120	292.4	310.6	5.3	492	376
NO.4	400	16	180	1.92	120	313.7	346.2	9	513	417
NO.5	400	24	220	2.77	105	306.7	325.1	5.5	441	370
NO.6	400	32	220	1.25	120	349.5	361	5.2	362	268
NO.7	415	16	220	2.77	120	310.7	326.2	4.6	510	370
NO.8	415	24	220	1.25	120	193.7	346.4	10.7	307	210
NO.9	415	32	180	1.92	105	243.2	303.1	6.9	471	417
NO.10	380	16	220	1.92	120	278.2	281.8	3.2	450	360
NO.11	380	24	180	2.77	120	311.7	320.2	4.8	487	340
NO.12	380	32	220	1.25	105	352.6	366.9	6.6	313	226
NO.13	400	16	220	1.25	120	337.4	358.7	7.6	270	199
NO.14	400	24	220	1.92	105	271.4	276.6	3	374	316
NO.15	400	32	180	2.77	120	369.3	380.3	7	558	476
NO.16	415	16	220	2.77	105	277.2	284.6	2.4	514	383
NO.17	415	24	180	1.25	120	338.2	365	7.7	310	212
N0.18	415	32	220	1.92	120	300.2	302.1	3.5	464	396

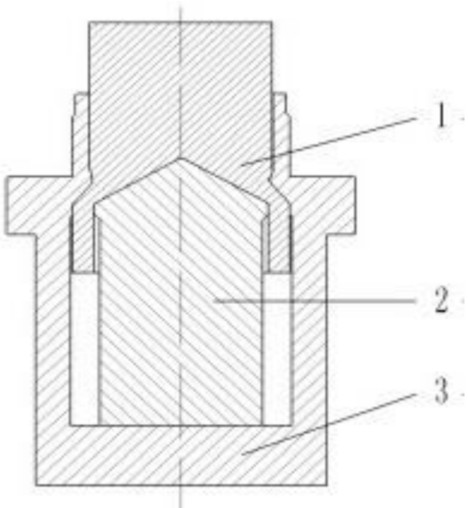


Figure 2. tube-expanding forming die. 1-billet; 2- core die;3-outer die

Figure 3. Specimen after forming.

3. Results and analysis

A series of comprehensive material performance tests of tube-expanding forming specimens were finished including tensile strength, yield strength and elongation percentage and microstructure.

According to extreme difference, in the level of this study, the parameters that affect yield strength are in the sequence as: HTB (47.5) > ER (39) > HT (34.9) > PTC (24.3) > ACD (6.58).

The sequence of tensile strength is: ER (64) > PTC (30.5) > HTB (20.1) > HT (18.3) > ACD (9.88). The sequence of elongation percentage is: ER (2.9) > PTC (2.4) > ACD (1.7) > HTB (0.9) > HT (0.1). The sequence of maximum extrusion pressure during tube forming is: ER (186.666) > ACD (43.333) > HT (39.666) > PTC (26.667) > HTB (9.666). The sequence of unloading pressure during tube forming is: ER (166.666) > HT (58.5) > HTB (30.667) > PTC (24.834) > ACD (22.333).

Compared with other parameters, extrusion ration has a significant impact on maximum extrusion pressure (MP) and unloading pressure (UP). An appropriate extrusion ratio means the pressure needed for forming decreased dramatically, crucial for reducing energy consumption and equipment loading. Among the entire scheme, the expanding tube possessing highest average tensile ultimate strength (380.0Mpa) and average tensile yield strength (369.3Mpa) were obtained from experiment NO.15, accompanied by 7% elongation percentage. As for elongation percentage, experiment NO.8 endowed the best ductility (10.7%) to the tube.

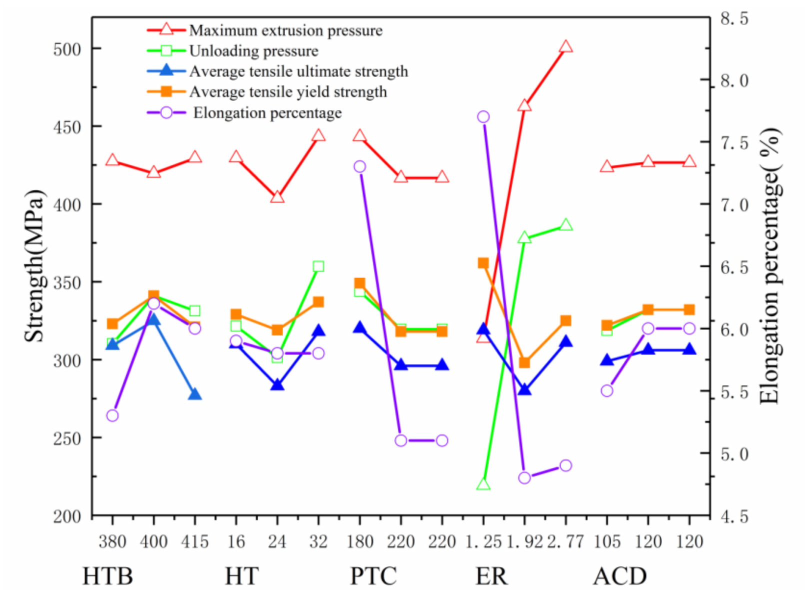
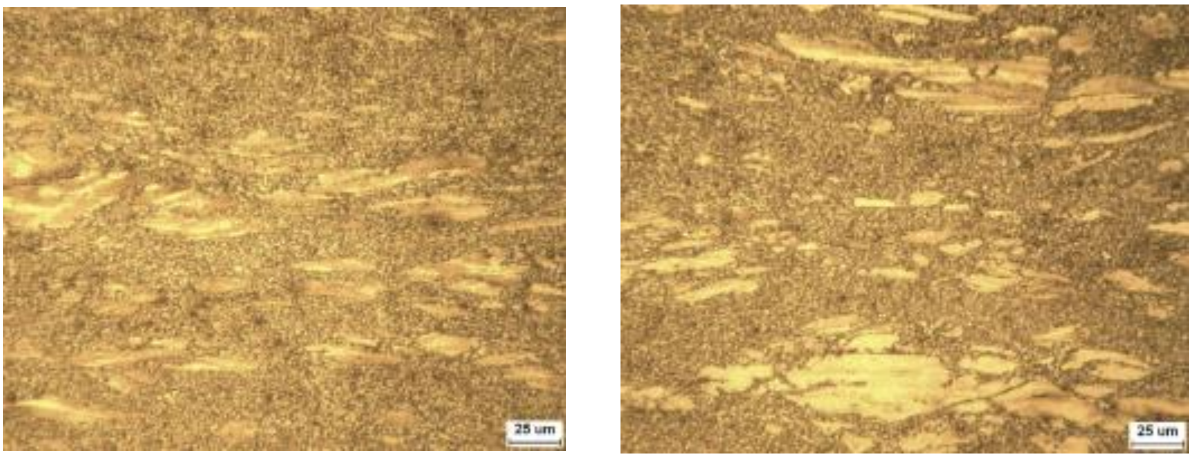


Figure 4. effects of key process parameters.

Further, the effects of these key process parameters on magnesium alloy expanding tube forming was summarized through orthogonal experiments, as shown in Figure 4. With the increase of homogenization temperature, the value of tensile yield strength, ultimate tensile strength and elongation percentage increases firstly and then decreases, reaching their peak value at 400 °. As homogenization time and extrusion ratio growing, the value of tensile yield strength, ultimate tensile strength and elongation percentage decreases firstly to a valley value at homogenization time 24h, extrusion ratio 1.92 correspondingly. Notice that the value of tensile yield strength, ultimate tensile strength and elongation percentage decreases as the preheating temperature of extrusion cylinder whereas increase with extrusion ration, which is also proved by process N0.17 and NO.18, process N0.7 and NO.16.

We also conducted series of Metallographic tests of the tube-expanding forming specimens. Metallographic structure of AZ80 magnesium alloy after hydrostatic extrusion is shown in Figure 5.



(a) cross section (b) vertical section

Figure 5. metallographic structure of AZ80 magnesium alloy after hydrostatic extrusion.

From Figure 5, the grain of magnesium alloy after hydrostatic extrusion is elongated along extrusion direction, with fine equiaxed grains increasing and grain refinement obvious. At the same time, a large number of twin and subgrain emerges that is difficult to distinguish between each other. It indicates that the deformation mechanism of the hydrostatic extrusion is dominated by twins, along with secondary twin forming. Under the interaction of twinning and basal slip, a part of twins distorts to twin dislocations and crystallite.

After extrusion, the coarse dendrites and columnar crystals were crushed and elongated. The subcrystalline structure is formed. Affected by extrusion stress and deformation heat, parallel fibrous structure shaped subcrystalline structure along grain boundaries. As a result, annealing recrystallization or other post-treatment processes is necessary for AZ80 magnesium alloy tube after hydrostatic extrusion in case to completely eliminate the bulk grain in the structure and thus greatly improve the ductility.

4. Summary

Through the analysis above, the influence of magnesium alloy ultra-high pressure hydrostatic extrusion process parameters on tube-expanding forming is obtained, which is very meaningful for further optimization and die design and production process. Meanwhile, the results of metallographic analysis indicate that after hydrostatic extrusion, specific heating treatment is essential for improving tube's ductility. According to all tests, experiment No. 13 is a more balanced choice for high tensile strength, yield strength and satisfying ductility underlow extrusion pressure. The study on further improving expanding forming tube's ductility with high tensile strength and yield strength is working on.

5. Acknowledgement
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6. References
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