

COLD DRAWING OF PURE MAGNESIUM WIRE

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Abstract:

Pure magnesium is a material with very high functionality, however, the cold drawing of this material is very difficult, because it has a hexagonal crystal structure and until this day there is no optimal cold wire drawing conditions. In this research, the goal is to create the optimal cold drawing conditions for pure magnesium wires. The first step is the investigation of the annealing temperatures by using tensile testing of the annealed wires, which will allow is to optimize the manufacturing of magnesium. Following the results listed below, the most suitable annealing temperature was 250°C for a reduction of 10% per pass. After the reaching the drawing limit and examining the drawn wires, cracks in the center of the wires, that is why suppressing their occurrence by applying a middle annealing to the process is needed. Consequently, it is possible to produce a cold fine drawn pure magnesium wire, without cracks or defects on the surface or hindering its medical properties.

Keywords: PURE MAGNESIUM, COLD WIRE DRAWING, ANNERLING, DIAMOND DIE

1. Introduction

Magnesium is a very light high functionality material that has high vibration absorbency, heat dissipation, electromagnetic wave-shielding and recycling efficiency. However proper cold wire drawing conditions haven't been establish, that is why warm or hot processing is commonly used. As a result, strength improvement of the wires is not possible, that is why the production of medical tools is disregarded. If it were possible to cold draw magnesium wires, the applications for material products would expand.

In this research, an investigation regarding the optimal cold drawing conditions of pure magnesium wire, the changes in the mechanical properties of the material after drawing and the problems that might occur during processing is conducted, the aim of which is to produce pure magnesium wire.

2. Preconditions and means for resolving the problem

2. 1. Tested wire and annealing conditions

Table1 shows the sample material and the annealing condition.

Table1 Tested material and annealing condition

Tested material	Pure magnesium
Diameter [mm]	2.58
Annealing conditions	300°C , 250°C , 200°C keep 1 hour

2. 2. Wire drawing process

In this research, the used material is pure magnesium wire with a diameter of 2.58mm. It was subjected to wire drawing with a reduction per pass (R/P) of 10%, 15% and 20%. The wire drawing process is explained in Fig. 1 and equations (1), (2). The drawing speed used was 300 mm/min, the drawing dies were tungsten carbide dies and diamond dies with a half-angle of 6 degree and for the wire drawing process teflon resin lubricant AGP8H and Na-soap powder were used.

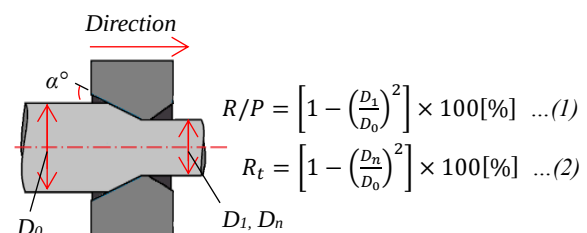


Fig.1 Definition of pass reduction and total reduction in wire drawing

$$R/P = \left[1 - \left(\frac{D_1}{D_0} \right)^2 \right] \times 100[\%] \quad \dots(1)$$

$$R_t = \left[1 - \left(\frac{D_n}{D_0} \right)^2 \right] \times 100[\%] \quad \dots(2)$$

3. Solution of the examined problem

In order, the present goal to be achieved, narrowing down the optimum drawing conditions for drawing of pure magnesium wires was needed. The low formability of pure magnesium prevents it from having a high drawing limit, following this, the improvement of the drawing limit can be achieved with proper annealing of the wires before and during the wire drawing processing, for that purpose the annealing conditions that were examined were 200°C, 250°C and

300 °C. The second thing that needed optimization was the reduction per pass, the following R/P were suggested for this experiment 10%, 15% and 20%. Finally, the last thing that needed confirmation was the material of the drawing dies, in this case the tested dies were tungsten carbide die and poly-crystal diamond die.

After comparing the different wire drawing conditions, an optimum drawing method was chosen and used in order to fabricate wires for medical tests.

4. Results and discussion

4. 1. Tensile test of the annealed pure magnesium wires

Firstly, tensile test was performed on the drawn pure magnesium wires, in order to investigate their mechanical properties, following this a Stress-Strain curve was build using the results. The Stress-Strain curves can be seen in Fig. 2.

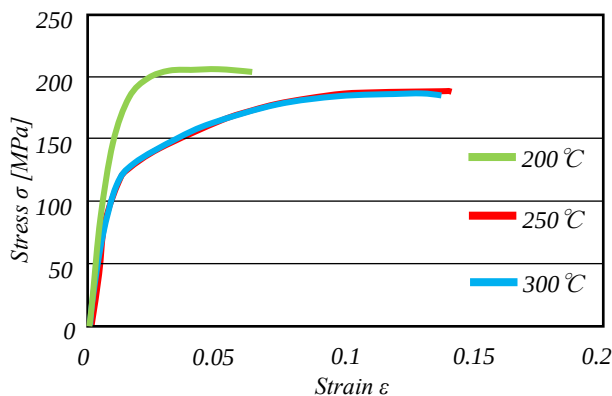


Fig.2 Stress-Strain curve of magnesium wire in tensile test

The highest tensile strength exhibited by the drawn wires was of 208.2MPa for the annealed wire at 200°C, compared to the 250°C with 187.6Mpa and 300°C with 186.8Mpa, but the elongation at fracture for that wire was only 3.87%, which is almost three times smaller than 11.5%(250°C) and 11.2%(300°C).

In the drawing processing, high ductility materials are more suitable for drawing than more brittle materials, following the results shown in Fig. 2, the most suitable annealing temperature for the drawing of pure magnesium wires is 250°C, based on the high elongation in tensile test.

In the SEM (Scanning Electron Microscope) image of the break side of the annealed wire, it can be seen that the 200°C and 300°C has a relatively brittle surface, compared to the 250°C wire, which has dimple fracture surface. It can be concluded that by using the 250°C annealing temperature, a high ductility material can be achieved.

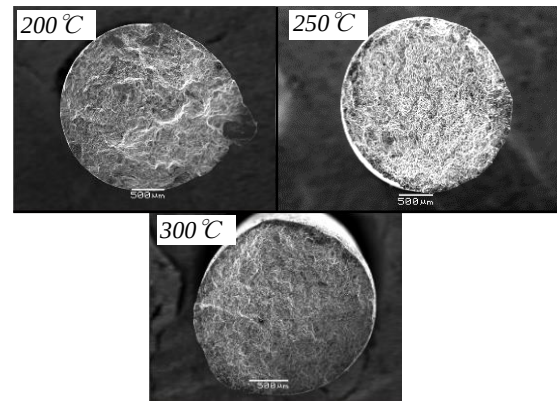


Fig.3 SEM image of magnesium wire surface after tensile test

4. 2. Changes of the drawing limit a wire with different annealing temperatures

In order to investigate the drawing limit of the pure magnesium, each of the annealed wires were used with the three different R/P and were drawn using tungsten carbide dies. The results are shown in Fig. 4.

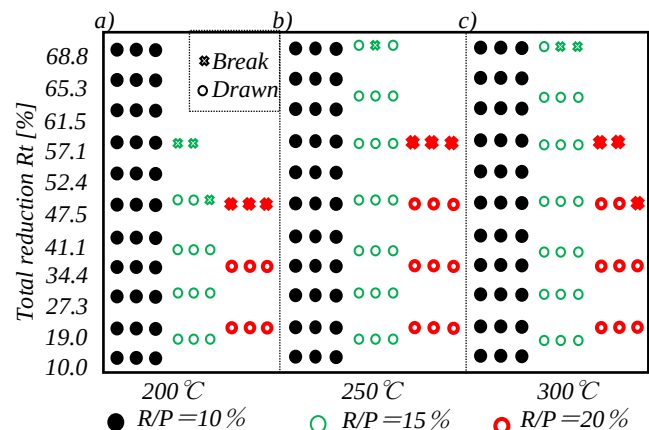


Fig.4 Drawing limits of magnesium wire

After drawing of all annealed wires, the wires that used 10% R/P were able to be drawn up to the goal of Rt=68.8%. For the 20% R/P the 200°C, 250°C and 300°C were drawn up to Rt=47.5% for 200°C and Rt=57.1% for 250°C and 300°C, but in the case of 300°C there was a breaking that occurred at the 47.5%, as the 250°C were successfully drawn until 57.1%. Finally for R/P of 15%, only the annealed wire at 200°C broke at Rt=56.1%, as the 250°C and 300°C were able to be drawn up to the drawing limit of Rt=68.8%, but in the 300°C's case two breaks occurred at the finishing diameter, but 250°C's case only one of the samples broke.

4. 3. Internal defect which is occurred in drawn wire

After drawing the pure magnesium wires while using the optimum drawing conditions that were chosen after the previous experiments – annealing temperature of 250°C, R/P=10%, , it was discovered that internal defect in the center of the wire occurred, as seen in Fig. 5.

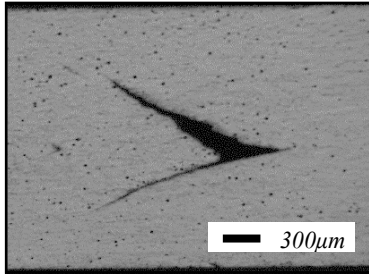
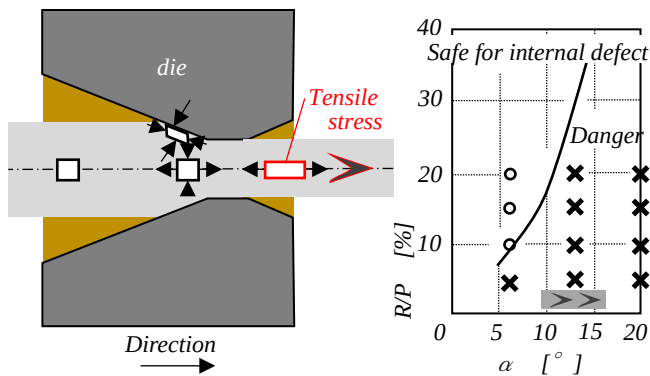


Fig.5 Internal defect in drawn wire

($\alpha = 6^\circ$, $R/P=10\%$, $R_t=68.8\%$)

Due to the occurrence of internal defect, cupping in the wire, it becomes unfit to be used as a production material.

Fig.6 Occurrence of cupping in the wire¹⁾

In Fig. 6 it is shown that the cause of inner cracks is due to the tensile stress in the center part of the wire. It is possible to suppress its occurrence by lowering the half-width of the die or by increasing the reduction per pass, because by the reduction of the friction force is necessary. Based on the graph in this Fig. 6, it was determined that any higher angle than 6° was unsuitable, also to further decrease friction diamond dies were suggested for this experiment.

4. 4. Drawing process using a diamond dies

Table 2 Difference in drawing stress between tungsten carbide dies and diamond dies

pass	Tungsten carbide dies [MPa]	Diamond dies [MPa]	Difference [%]
1	55	48	12.7
3	66	62	6.1
5	70	67	4.3

In Table 2, the drawing stress using tungsten carbide and diamond dies, for reduction of 10% can be seen, the diamond dies had a lower drawing stress of about 7-8%. After drawing the pure magnesium wires annealed at 200°C , 250°C and 300°C while using R/P of 10%,

reaching the drawing limit of $R_t=68.8\%$ was possible for all wires, that is why in order to compare the increase of drawing limit and decrease of drawing stress by using diamond dies, the R/P used was 20% to establish the effectiveness of using diamond dies. In this case, the results can be seen in Fig. 7.

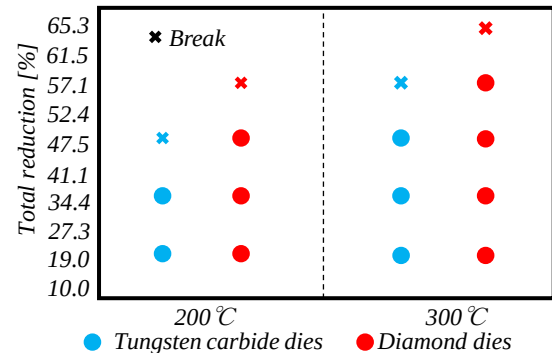


Fig.7 Drawing limits of magnesium by using a diamond dies

($\alpha = 6^\circ$, $R/P=20\%$)

Furthermore, after drawing the wire to $R_t=68.8\%$ with a $R/P=10\%$ and annealing temperature of 300°C , the finishing wires were examined by using SEM, in order to observe the difference between the drawn wires' surfaces between the tungsten carbide and diamond dies. The results can be seen in Fig. 8.

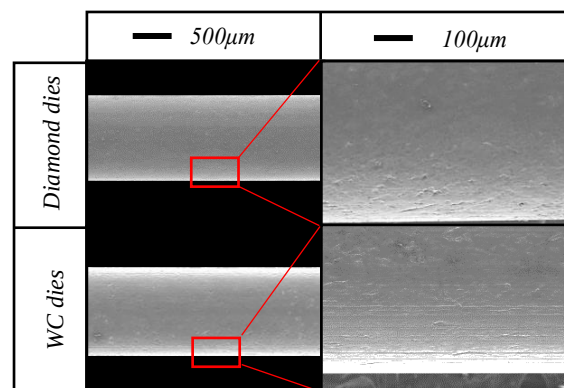


Fig.8 SEM image of drawn wire surface with the WC dies and diamond dies ($\alpha = 6^\circ$, $R/P=10\%$, $R_t=68.8\%$)

There are many defects on the surface of the tungsten carbide die drawn wire, such as surface flaw and die marks, after reaching the drawing goal, but in the case of the diamond die, after drawing it exhibits much finer surface compared to the tungsten carbide die and a lack of die marks.

Following this, it can be concluded that the diamond dies present much better effectiveness for drawing of pure magnesium wires, with higher drawing limit, lower drawing stress and a finer surface of the finishing drawn wire, but even after the application of diamond dies, the occurrence of cupping still persisted, which led to the introduction

of an intermediate annealing for further increasing the workability of the material.

4. 5. Effect of the intermediate annealing

The drawing of pure magnesium wires with two intermediate annealing points ($R_t=34.4\%$ and $R_t=57.1\%$) and a single intermediate annealing point ($R_t=34.4\%$; $R_t=41.1\%$; $R_t=47.5\%$), were examined for a total reduction of $R_t=68.8\%$ and the changes of mechanical properties were summarized in the stress-strain diagram of Fig. 9.

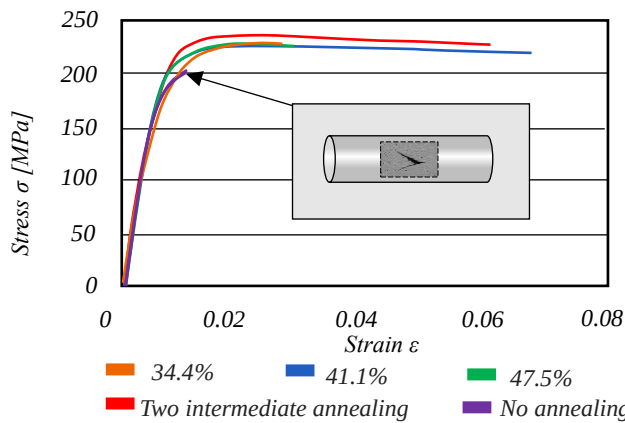


Fig.9 Stress-Strain curve of intermediate annealed wire ($R_t=68.8\%$)

In the case of single annealing with $R_t=41.1\%$, the elongation at fracture was about 0.067 and total tensile strength was around 230Mpa. The case of the two intermediate annealing the tensile strength was higher by comparison with 237Mpa, but the elongation at fracture was 0.06, which is lower than the single annealed wire at $R_t=41.1\%$. Also in the case of all other annealed wires, the tensile strength of the drawn finishing wire was close to the previously mentioned wires, but the elongation at fracture was much lower. Following these results, the annealing most suitable for this wire drawing, is the single annealing at $R_t=41.1\%$

In addition, it the inner section of the drawn wires were checked to confirm the presence of defects in the center of the drawn wires. In Fig. 10, the comparison between intermediate annealing of $R_t=41.1\%$ and $R_t=47.5\%$.

After observing the wire drawn with an intermediate annealing with $R_t=47.5\%$, it was determined that just like the case of Fig. 5, it exhibits cupping in the center of the wire, rendering it unsuitable for production of medical tool. In the case of the $R_t=41.1\%$, after closely examining the center of the drawn wire along its length, no trace of cupping was spotted. Based on this, it was concluded that by using intermediate annealing of $R_t=41.1\%$ for cold drawing of pure magnesium with a total reduction of $R_t=68.8\%$, the occurrence of

cupping can be prevented, leading to a more suitable material for the needed purposes.

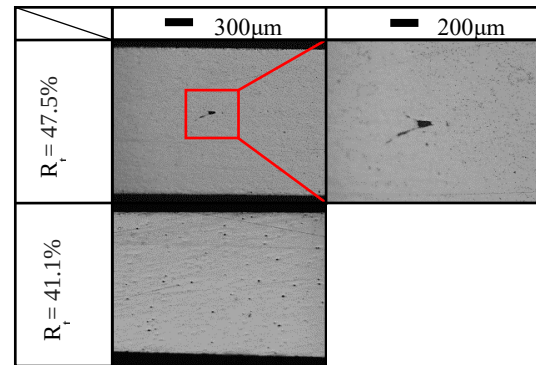


Fig.10 The internal defect that occurred to the annealed drawn wire ($R_t=68.8\%$)

5. Conclusion

For the wire drawing of pure magnesium, the most suitable annealing temperature was decided at $250\text{ }^{\circ}\text{C}$, and very effective means is using a diamond die, also by using a diamond die, a reduction per pass of 10% and by performing an intermediate annealing at a cross-section reduction rate of 40%, it was possible to achieve a diameter of 1.44, without the occurrence of inner cracks in the center of the wire, which is suitable for the production of medical tools.

6. Reference

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