Experiment and ANSYS simulation analysis for metal aluminum solid and fluid conversion

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Abstract. In this paper, study on metal aluminum solid and fluid conversion was carried out by using crucible resistance furnace, and observing the phenomenon of metal aluminum solid and fluid conversion. In the experiment, the same shape aluminum block was kept under the same heating rate and heated by the resistance furnace. The experimental results show that the melting point of metal aluminum is between 650°C and 660°C, and after the melting point, the metal aluminum began to melt when it maintained for a long period of time, however, when the temperature is higher than the melting point, the aluminum will melt very quickly. In addition, in ANSYS simulation, the solid aluminum melted completely at 670°C in 5430 seconds, much longer than the actual experiment, it due to the heating rate was faster, not in an ideal experimental environment and there is heat exchange with the outside world and convection, at the same time, the aluminum block may contain impurities, so the actual melting time could be shorter than the simulation. In this paper, it was explored for the liquid and solid conversion in depth, and had a certain actual value.

1. Introduction
With development and progress of the society, the demand that people need energy was growing gradually, and people faced the current situation that shallow resources are exhausted [1]. Therefore, it is very urgent to explore deep energy, but researches of domestic and foreign scholar suggested that the deep mining environment problem was very complex, there exist factors such as high temperature, complex stress field and it makes the difficulty of deep mining increase [2-4]. To solve these problems, we carry out simulation experiments with various kinds of existing materials to study the problem of solid flow transformation of deep soft rock, thus reducing the difficulty of mining.

The solid and fluid material conversion refers to material change process between solid and fluid under effect of the external environment factors, such as the storage of foods like sugar and chocolate [5,6], the melting of ice, snow [7] and metal [8]. In this paper, solid and flow conversion experiment for metal aluminum was carried out using the crucible resistance furnace, the phenomenon of solid and fluid conversion was particularly described through the molten experiment of metal aluminum. The finite element simulation experiment of the solid flow transformation of metal aluminum has also been carried out in this paper, and some valuable conclusions have been obtained [9-11].

2. Transformation experiment between solid and flow of aluminum
It is common to metal melting and crystallization in the daily life and industrial production, its essence is that the internal metal mutual conversion between solid and liquid crystal. However, because the
metal melting temperature is higher, there are almost no special experiments about metal conversion of solid and fluid, and in this paper, the metal aluminum solid and fluid conversion experiment was carried out by using the crucible resistance furnace.

2.1. Experimental equipment
6061 aluminum, DRZ-4 resistance furnace temperature controller, G2-5-10 crucible resistance furnace, crucible, 50 mm (long) X 50mm (wide) X 80 mm (high) aluminum block, hand-held infrared thermometer, ruler, sandpaper, experimental units, thermometer, screwdriver, wire, socket, etc.

2.2. Experimental scheme
Experimental scheme 1: Put the aluminum blocks into the graphite crucible, carry out melting experiments in crucible resistance furnace, find the aluminum melt temperature through slowly heating up, rerun the experiment, make the aluminum blocks melt under the temperature when the aluminum started to melt, observe the phenomenon of the aluminum melt, record experimental data, and record the time required that the aluminum melted completely under this temperature and the time required for complete solidification of the liquid aluminum at room temperature is then recorded.

Experimental scheme 2: put the same shape aluminum blocks into a crucible, carry out melting experiments in resistance furnace, make aluminum blocks separately heat to the temperature that 10 degrees higher than the temperature of aluminum blocks started to melt, observe the phenomenon of the aluminum melting, record experimental data, and the time needed for complete melting of the aluminum block is recorded separately.

2.3. Experimental steps
Equipment connection: connect the DRZ-4 resistance furnace temperature controller to the SG2-5-10 crucible resistance furnace with wires; the temperature sensor is placed in the crucible. Place the installation in ventilation safety position, as shown in figure 1.

Material placement: First, putting aluminum and crucible into the electrical resistance furnace, covering the furnace cover, and then switch on the power supply.

Heating: Making the crucible resistance furnace heat through temperature controller, and keep a constant temperature, observe whether aluminum has be soft and started to melt or not, and recording the experimental data. Finally finding the time points of aluminum started to melt, and recording the temperature at this time [12-14].

When aluminum completely melt into liquid, as shown in figure 2, close the device and observing the process which aluminum changes from liquid to solid, make the liquid aluminum with extremely slow speed to cool in the crucible, in the process of cooling, every once in a while measuring a temperature, and record it. When the aluminum becomes solid and the crucible furnace drop to room temperature, take out the crucible and the solidified aluminum block.
3. Experimental data and experimental conclusions

3.1. Experimental results
The experimental results are shown in tables 1-3.

Table 1. The relationship between the melting time, temperature and the state of molten aluminum.

| Time (min) | Temperature (°C) | Status     |
|-----------|------------------|------------|
| 1         | 0                | solid      |
| 2         | 10               | solid      |
| 3         | 15               | solid      |
| 4         | 19               | solid      |
| 5         | 23               | solid      |
| 6         | 28               | solid      |
| 7         | 35               | solid      |
| 8         | 40               | solid      |
| 9         | 45               | solid      |
| 10        | 50               | solid      |
| 11        | 55               | solid      |
| 12        | 60               | solid      |
| 13        | 65               | solid      |
| 14        | 84               | liquid     |
| 15 Close the resistance | 85         | liquid     |
| furnace   | 90               | solid-liquid mixed |
| 16        | 100              | solid-liquid mixed |
| 17        | 114              | solid      |
| 18        |                  |            |

Table 2. The relationship between the melting time, temperature and the state of molten aluminum.

| Time (min) | Temperature (°C) | Status               |
|-----------|------------------|----------------------|
| 1         | 0                | solid                |
| 2         | 10               | solid                |
| 3         | 14               | solid                |
| 4         | 20               | solid                |
| 5         | 25               | solid                |
| 6         | 32               | solid                |
| 7         | 40               | solid                |
| 8         | 43               | softening            |
| 9         | 45               | solid-liquid mixed   |
| 10        | 55               | solid-liquid mixed   |
| 11        | 65               | liquid               |
| 12 Close the resistance | 65         | liquid               |
| furnace   | 75               | solid-liquid mixed   |
| 13        | 85               | solid-liquid mixed   |
| 14        | 90               | solid                |
| 15        |                  |                      |

Table 3. The relationship between the melting time, temperature and state of molten aluminum.

| Time (min) | Temperature (°C) | Status |
|-----------|------------------|--------|
|           |                  |        |
3.2. Experimental conclusions

- From table 1, it can be seen that the rise of temperature is linear. The metal aluminum softening phenomenon began to appear at 650°C, and it is in a solid-liquid mixed state at 660°C. It indicates that the melting point of metal aluminum is in the middle of 650-660°C, which was consistent with the theory.

- From table 2, it can be seen that the metal aluminum began to melt at 660°C. It took 19 minutes to complete the melting. From the beginning of the heating to the end of the melting, it lasted 65 minutes. The liquid aluminum solidified into solid aluminum in about 25 minutes, and the temperature of the aluminum in solid-liquid mixed state is lower than the melting point of aluminum, this phenomenon is what we call supercooling.

- Comparing tables 2 with 3, it can be seen that the metal aluminum cost a total of 12 minutes from the beginning to the end of the melting at 670°C, less than the melting time at 660°C, which indicates that the higher the heating temperature is, the faster the aluminum melts.

4. Numerical simulation analysis

The phase change analysis module in ANSYS software is adopted in this paper, it mainly regarded the enthalpy as material attribute definition, the phase could be distinguished through temperature. By phase change analysis, the temperature distribution of the material at each moment can be obtained. Through the temperature nephogram, we could get the time required for complete phase change (melting or solidification time). The analysis process consists of the following steps: (1) Pre-processing, namely creating finite element model of metal aluminum, dividing grid units, carrying out temperature load and constraint condition; (2) Solving, set the solution option and time steps, and then solve; (3) Post-processing, checking the temperature distribution nephogram, inspecting test results.

4.1. Description of problems in metal aluminum melting test

The melting process of aluminum is analyzed, putting the aluminum block with size of 50 mm (long) X 50 mm (wide) X 80 mm (high) into the crucible and then melt in the crucible resistance furnace, the initial temperature of the aluminum and environment are room temperature, from time is equal to zero start to load 670°C for metal aluminum, ignoring the influence of air and crucible. The material parameters of metallic aluminum are shown in table 4, when analyzing, the temperature unit used °C, other units used pharmaceutical units. Through Phase transformation analysis of ANSYS, the time how long does the metal aluminum blocks melt complete need under this temperature was obtained.

The phase transition analysis of metal aluminum block is carried out using SOLID70 thermal analysis unit of three-dimensional eight node, an imperial unit is used during the analysis.
Table 4. The material parameters of aluminum.

| Temperature /°C | Enthalpy /J/m³ | Solid specific heat capacity /J/kg•°C | Liquid specific heat capacity /J/kg•°C | Density /kg/m³ | Melt point /°C |
|-----------------|----------------|--------------------------------------|--------------------------------------|----------------|----------------|
| 0               | 0              | 896                                  | 1050                                 | 2707           | 660            |
| 659             | 1.5984e9       |                                      |                                      |                |                |
| 661             | 2.6747e9       |                                      |                                      |                |                |
| 1000            | 3.6382e9       |                                      |                                      |                |                |

4.2. Analysis of the aluminum melting time course
From figure 3, it could be obtained when the metal aluminum melting time were 2000 s, the highest temperature was 433°C and the minimum temperature was 358°C. And it still in solid state.

From figure 4, it could be obtained when the metal aluminum melting time were 3000 s, the maximum temperature was 631°C and the lowest temperature was 576°C. At this time, it still in solid state, but it already very close to the melting point of aluminum blocks.

From figure 5, it could obtained when the metal aluminum melting time were 3600 s, the maximum temperature of 660°C and the lowest temperature was 610°C, at this time, the solid state aluminum has already started to melt.

From figure 6, it could obtained when the metal aluminum melting time were 5430 s, the highest temperature was 694°C and the minimum temperature was 652°C, the melting of solid state aluminum had accomplished basically.

![Figure 3](image1.jpg)  ![Figure 4](image2.jpg)  
**Figure 3.** Temperature distribution of the aluminum block in 2000 seconds.  
**Figure 4.** Temperature distribution of the aluminum block in 3000 seconds.  

![Figure 5](image3.jpg)  ![Figure 6](image4.jpg)  
**Figure 5.** Temperature distribution of the aluminum block in 3600 seconds.  
**Figure 6.** Temperature distribution of the aluminum block in 5430 seconds.
In summary, it could be obtained through the whole temperature distribution nephogram of metal aluminum under different melt time, when the melting time was 1000 s, due to the temperature is lower, the aluminum blocks have not yet started to melt; When the melting time was 3600 s, the aluminum blocks began to melt, and the face loaded of the aluminum blocks started to melt; When the melting time were 5430 s, the minimum temperature closed to 660°C, it shown that the aluminum blocks have melted completely.

5. Conclusions
In this paper, we got the time and temperature parameters of aluminum block melting and crystallization through the comparative analysis by the solid-flow transformation experiment of aluminum and ANSYS numerical simulation analysis. It was founded that the important factor influenced the aluminum solid and fluid conversion was temperature, the metal aluminum melting temperature is between 650°C and 660°C. The time were 20 minutes or so, which the solid metal aluminum need to transformed to liquid completely under 660 temperature, it also suggested that the melting rate will be faster when the aluminum melting temperature higher than the melting point. It is useful for the research in this field and has important application value.

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