Development and experimental research of aluminium alloy droplet generator based on mechanical vibration

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Abstract

In order to produce aluminium droplet stably, a novel droplet generator based on mechanical vibration was developed. The generator was made up of vibration exciter, vibration rod, graphite crucible, cooling channel and some other components. Droplet generating experiments were conducted to study the influence of parameters on droplet formation. The results indicated that single droplet could not be generated without mechanical vibration. By applying mechanical vibration, single droplets were generated while backpressure was between 34 and 40 kPa. While single droplets were generated, the mean diameter was 828.4 \( \mu \)m which was approximately 2.1 times of the nozzle diameter. The standard deviation was 33.8 \( \mu \)m indicating that the droplets were uniform. As a result, the capability of the generator for generating aluminium droplet was validated.

1. Introduction

As a novel rapid prototyping technology, micro metal-droplet deposition manufacture is attracting increasing interest due to its advantages of low cost, high material usage efficiency and wide range of material selection. It has

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great potential applications in automotive, electronics and other industry fields. During the technique, how to generating droplet stably is one of the key issues which limit the application of MDDM and it needs to be solved. In present. many researches which aimed to generate droplet stably have been reported. Based on different driven mode, the droplet generator was divide into several categories including pneumatic driven generator, piezo activated generator and electromagnetic force driven generator. Cheng et al. (2005) developed a pneumatic droplet generator. Droplets of molten indium, tin, lead, bismuth and zinc were produced. Zeng et al. (2010) also developed a pneumatic drop-on-demand generator and succeed producing aluminium droplet. Taik-Min et al. (2008) developed a drop-on-demand generator by using piezoelectric actuator and solder droplet with 200μm diameter were produced. Wang et al. (2007) proposed a novel droplet generator based on electromagnetic force driven mode and produced micro solder droplet. However, the generators referred above had their own defects. Pneumatic driven generator was difficult to generate droplet stably long time because that the pressure in the crucible varied as the volume of liquid decreased if the supply pressure was kept constant. Piezoelectric actuator could not work at high temperature due to the low Curie temperature of the piezoelectric material. The electromagnetic force driven generator needed greater magnetic field strength for ejecting metal which had high viscosity and surface tension. Aluminium has high melting point, high viscosity and surface tension. Thus it is imperative to develop a novel generator for producing aluminium.

In present work, a droplet generator based on mechanical vibration was developed. A retrofit solenoid valve was used as a vibration exciter. The droplet generator included vibration exciter, vibration rod, graphite crucible, cooling channel and several other components. Aluminium droplets were generated stably by using the generator and the influence of backpressure on droplet generation was studied.

2. Principle of mechanical vibration droplet generator

Fig. 1 shows the schematic of droplet formation. First, pulse mechanical vibration was generated by a retrofit solenoid valve and transfered to a vibration rod. Then the vibration rod moved downward and the molten aluminium liquid was extruded out from the nozzle forming a liquid column. After the pulse vibration eliminated, the vibration rod move upward and the liquid column breakup to form a droplet. During the process, argon gas was flowed into the crucible and was applied on the molten metal. The backpressure was useful for droplet generating.

3. Structure design of vibration droplet generator

Based on the mechanism of droplet formation, a mechanical vibration driven droplet generator was developed. Fig. 2 showed the schematic diagram and photo of the generator. The generator inculded vibration exciter, vibration rod, adjusting compenents, graphite crucible and cooling channel.
Fig. 2. (a) Schematic diagram of droplet generator and (b) photo of droplet generator.

(1) Vibration exciter
A retrofit solenoid valve was used as a vibration exciter which was made up of an electromagnetic coil and an iron rod. The vibration exciter was controlled by a drive circuit. While pulse signal generated by the function generator, current flowed through the electromagnetic coil and the iron rod was driven to move downward. The vibration frequency was 10Hz in present study.

(2) Vibration rod and adjusting component
The vibration rod was struck by the iron rod and moved downward to compress the metal liquid near the nozzle. After the strike, driven by a spring the vibration rod would move upward to the initial place. Adjusting components was used to change the distance between vibration bottom and nozzle. The distance was 3mm in present study.

(3) Graphite crucible
The crucible was made of graphite because that the graphite had high melting temperature and it was difficult to be corroded by the aluminium liquid. The distance between the crucible wall and the vibration rod wall was controlled by the diameter of the vibration rod. It was 2mm in present work.

(4) Cooling channel
The cooling channel was palced between the crucible and the vibration exciter. It was used to keep the electromagnetic coil at appropriate temperature.

3. Experiment result and discussion

3.1. Experiment method

In order to validate the capability of the droplet generator, droplet generating experiment were conducted by using Z1102. The nozzle was made of graphite which had good corrosion resistance. As shown in Fig. 3(a), the nozzle orifice had good roundness and there was no impurity in the orifice as shown in Fig. 3(b). In present work, the diameter of the nozzle orifice was 400μm. In addition, the oxide skin on blank was removed. During experiment, the crucible was heated to 850°C to melt the aluminium alloy.
3.2. Effect of backpressure on droplet formation

In present work, two sets of experiments were conducted to study the influence of parameters on droplet formation and obtain the appropriate parameter values. As shown in Table 1, backpressure was adjusted from 0 to 50 kPa. In the first sets of experiment, mechanical vibration was not used and in the second set of experiments mechanical vibration was used. During the second set of experiments, mechanical vibration was generated by pulse signals with 10ms pulse width and the frequency was 10Hz. Table 1 also showed the different phenomena obtained in different conditions.

<table>
<thead>
<tr>
<th>Backpressure (kPa)</th>
<th>Mechanical vibration off</th>
<th>Mechanical vibration on</th>
</tr>
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<tbody>
<tr>
<td>0–30</td>
<td>No droplet</td>
<td>No droplet</td>
</tr>
<tr>
<td>31–45</td>
<td>No droplet</td>
<td>Single droplet or multiple droplets</td>
</tr>
<tr>
<td>&gt;46</td>
<td>Jetting flow</td>
<td>Jetting flow</td>
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</tbody>
</table>

According to the results shown in Table 1, while there was no mechanical vibration, only two phenomena occurred: no droplet and jetting flow. It was necessary to use mechanical vibration for single droplet generating. Droplets generated in different conditions also were collected by using an asbestos container and the droplet diameters were measured to study the influence of backpressure. In the next section, the phenomena which occurred in the second set of experiments were discussed.

(1) No droplet

Although mechanical vibration was applied on molten metal, no droplet was generated while backpressure was smaller than 30 kPa. In these conditions, the resultant of force formed by the gas pressure and the vibration of the rod was not enough to overcome the resistance and extrude the liquid out of the nozzle.

(2) Single droplet (occasionally)

By increasing backpressure from 31 kPa to 33 kPa, single droplet was generated occasionally. In this value range of backpressure, one droplet was generated by applying several pulse signals. Fig. 4 showed the photo of the droplet generated and diameters were measured. The mean diameter was 916.4μm and the standard deviation was 113.7 μm indicating that the droplets were nonuniform.
(3) Single droplet (stably)

While backpressure was between 34 and 40 kPa, single droplet could be generated in each pulse signal. In these conditions, the mean diameter of droplets was 828.4 µm. The standard deviation was 33.8 µm and it indicated that the droplets were uniform and the droplet generation was stable.

(4) Several droplets

While backpressure varied between 41 kPa and 45 kPa, several droplets were generated by one pulse vibration. In these conditions, the resultant of force formed by the gas pressure and the vibration of the rod was too large and the liquid column was too long resulting in that more than one droplet would be generated during one pulse vibration. The mean diameter and the standard deviation were 887.2 µm and 60.7 µm, respectively.
(5) Jetting flow
While backpressure was larger than 46 kPa, due to the large gas pressure the molten metal was extruded from the nozzle and jet flow was formed. In these conditions, single droplet could not be produced.

4. Conclusions

A novel droplet generator based on mechanical vibration was developed in present work. According to the results referred above, it was validated that aluminium droplets could be produced by using the droplet generator and appropriate parameters for generating single droplet were obtained. Several conclusions were drawn as follows:

(1) Mechanical vibration was the necessary requirement for generating single droplet;
(2) While backpressure was between 34-40 kPa, single droplet was generated stably by applying mechanical vibration;
(3) While single droplets were generated, the mean diameter of the droplets was $\mu m$ which was approximately 2.1 times of the nozzle diameter.

Also, previous research has indicated that the vibration amplitude, vibration waveform had influence on metal droplet generation (Ma, 2014). In the future, systematic study would be conducted to study the influence of some process parameters.

Acknowledgments

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References

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