Research on Melt Degassing Processes of High Conductivity Hard Drawn Aluminum Wire

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Abstract. Degassing effects of ultrasonic and vacuum processes on high conductivity hard drawn aluminum melt were studied. Results showed that the degassing efficiency improved with the increase of ultrasonic power within certain range, stabilizing at 70% with 240W. For vacuum degassing process, hydrogen content of aluminum melt decreased with the loading time and was linear with logarithm of vacuum degree. Comparison of degassing effects of ultrasonic, vacuum, vacuum-ultrasonic degassing process showed that vacuum-ultrasonic process presented optimal effect.

1. Introduction
Reducing power loss of overhead transmission line has increasingly gained focus of attention of electric power industry, and application of new type energy-saving wire was one of key technologies[1-3]. Due to high conductivity and good mechanical properties, high conductivity hard drawn aluminum wire has been widely used in transmission line for low resistance loss and significant energy-saving benefits. However, the complicate preparation process and high production cost restricted its development and wide spread application severely. Therefore it is very necessary to develop high conductivity hard drawn aluminum conductor with good properties and low cost on which few researches were carried out.

In this paper, industrial pure aluminum with optimized chemical composition was adopted as raw material in order to decrease production cost. Because unavoidable existence of inclusions and gas in aluminum melt, mainly Al2O3 and H2, will lead to deterioration of properties, melt purifying processes were introduced to improve the conductivity and strength. At the present, three-stage refinement process was commonly used to improve purity of aluminum melt. The first stage was furnace refining, adding flux to remove a majority of coarse inclusions (several hundred µm in diameter). During secondary refining a quantity of inert gas-chlorine mixture bubbles were blown into aluminum melt, then dissolved hydrogen entered bubbles due to its zero partial pressure, and inclusions were removed by trapping effect of bubble on them. As for the removal ability for tiny inclusions with dimension of 30-100µm, the third stage of advanced purification was very important to increase aluminum melt purity, generally using foam ceramic filter.

Researches points out that ultrasonic vibration and vacuum degassing are beneficial to refine grain, remove gas and inclusion as well as prevent segregation. But studies on these purification processes appropriate for industrial pure aluminum remained little. In the present work, the influences of purification processes, including ultrasonic vibration, vacuum degassing and foam ceramic filter, on high conductivity hard drawn aluminum melt using industrial pure aluminum as raw material were...
discussed, and optimized parameters were provided to guide the production of high conductivity hard drawn aluminum wire.

2. Experimental Materials and Procedure

2.1. Experimental Materials

The chemical composition of the examined materials was shown in Table. 1.

Table. 1 The chemical composition of the experimental material (wt%)

|   | Si   | Fe   | Cu   | Mn   | Mg   | Cr   | Ni   | Zn   |
|---|------|------|------|------|------|------|------|------|
|   | 0.026| 0.047| 0.0006| <0.0003| 0.0013| 0.0008| <0.0004| <0.0010|
| Ti | <0.0004 | Ag  | B    | Ba   | Be   | Bi   | Ca   |      |
| <0.0004 | <0.0001| 0.0001| <0.0001| 0.0002| <0.0010| 0.0013|      |
| Ce | <0.0015| Co  | Ga   | In   | Li   | Na   | P    |      |
| Sb | <0.0020| Sn  | Sr   | V    | Zr   | Hg   | Al   |      |
|    | 0.0021| <0.0001| 0.0031| <0.0003| <0.0020| 99.9061|      |

2.1.1. Experimental Procedures. The density of aluminum melt was measured by weighing method as follows: Firstly, weigh the mass of aluminum melt in air as M1. Secondly, weigh the aluminum mass in water as M2. Hence the mass of aluminum melt was equal to M2-M1. The aluminum density could be obtained according to equation. 1.

\[
\rho_{Al} = \frac{\rho_{H_2O} \times M1}{(M2-M1)}
\]  

(1)

The gas content was obtained by calculating the ratio of gas pore area to total area. Fig. 1 gave a SEM graph of a certain experimental aluminum melt sample. Gas pore area was examined using picture recognition software, and gas pore area proportion was obtained by dividing total area by gas pore area.

Fig. 1 SEM of experimental aluminum melt sample

The ultrasonic purify process of aluminum melt was studied during load ultrasonic experiment. The experimental apparatus was illustrated in Fig. 2. The ultrasonic wave was loaded on aluminum melt with different frequency of 105W, 135W, 200W and 240W for 0.5min, 1min, 2min, 3min, 5min and 8min respectively, then density of after-treated aluminum melt was measured. Relationship between hydrogen degassing efficiency and time under different ultrasonic power was studied.
Fig.2 Diagram of ultrasonic experiment apparatus

Vacuum degassing experiment was carried out by ZG-3 vacuum induction melt furnace. Hydrogen content was measured through melt density. Results of processes including different vacuum degree and time were analyzed, and relationship between process parameters and degassing effect was discussed.

3. Experimental Results and Discussions

3.1. Relationship between Hydrogen Content and Aluminum Melt Density

To study the effect of ultrasonic wave on hydrogen degassing efficiency, the relationship between aluminum melt density and gas content was firstly discussed. The aluminum melt density was measured by weighing method. The gas pore area percent was calculated by graph recognition software. Through data processing it was found that aluminum melt density presented a linear relationship with gas pore area percent as shown in Fig.3, so gas content in aluminum melt could be concluded by density, hence hydrogen content could be obtained because 90 percent of gas was hydrogen.

Fig.3 Relationship between aluminum melt density and gas pore area percent

Examination results showed that gas content related directly with aluminum melt density. Further experiment was carried out by increasing gas pore quantity through adding water, the relationship between density and hydrogen content in large range was given in Fig.4.
3.2. Relationship between Hydrogen Degassing Efficiency and Time under Different Ultrasonic Power

Ultrasonic waves with different frequency were loaded on aluminum melt and density of melt sample was measured. The result after data handling was shown in Fig.5. It could be seen from Fig.5 that hydrogen degassing efficiency improved with increasing of power during experimental power range of 0-240W. When the power was 105W, hydrogen degassing efficiency stabilized at 38% with 8min, whereas reached 70% with 4.8 min.

Research found that ultrasonic wave has liquid purifying effect. Experimental results indicated that ultrasonic wave has significant potential to metal melt degassing through comparison of four kinds of degassing processes including chlorine gas, ultrasonic wave, vacuum-ultrasonic and vacuum. All of these studies pointed out that ultrasonic degassing of aluminum melt were closely related to ultrasonic power and void effect. According to ultrasonic purifying principle, when ultrasonic field was loaded on aluminum melt, the melt structure integrity and continuity were destructed through cavity effect and a lot of tiny voids emerged. Hydrogen solute in melt escaped to these voids and formed bubble nucleus, then gradually growing to bubbles and came out melt surface, implementing hydrogen
degassing course. When the ultrasonic power was large enough, its effect range could cover whole melt. Hydrogen degassing result was satisfactory due to elimination of both macro and micro bubbles, so good aluminum melt was obtained.

3.3. Research on Vacuum Degassing Process of Aluminum Melt

Influences of vacuum degree on aluminum melt density were studied. The hydrogen content could be obtained by measuring melt density. Densities of samples under different vacuum degree for different time were examined to calculate hydrogen content. Effects of degassing time and vacuum degree on hydrogen content were shown in Fig.6. Relationship between vacuum degree and hydrogen content was concluded by data processing as illustrated in Fig.7.

![Fig.7 Relationship of different vacuum degree on hydrogen content](image)

It could be seen from Fig.6 that hydrogen content of aluminum melt decreased with increasing of degassing time till strike a balance after 20min and changed no longer after 45min. From Fig.7 it can be seen that hydrogen content was linear with logarithm of vacuum degree, therefore the lower the remnant pressure, the smaller the hydrogen content. However, vacuum degree should be considered combining industrial cost because it was limited by equipment conditions.

3.4. Researches of Process Combining Vacuum and Ultrasonic Wave Degassing of Aluminum Melt

The influences of vacuum degassing combining ultrasonic wave on hydrogen of aluminum melt were studied. Vibrator was installed in the furnace hole and sealed. When the vacuum degree reached 1torr,
ultrasonic wave with frequency of 20kHz was loaded with vacuum degree unchanged, then cooled, opened the furnace and casting quenching. The effects under different degassing processes of vacuum, ultrasonic wave and combination of ultrasonic wave and vacuum were compared. The result was shown in Fig.8. It could be seen that the degassing time of combination process reduced remarkably and showed satisfactory degassing effect.

Fig.8 comparison of degassing effects among ultrasonic degassing, vacuum degassing and combination degassing of ultrasonic and vacuum

Researches pointed out that effect of ultrasonic degassing depended on time, physical parameters and initial hydrogen content of aluminum. Combination of ultrasonic and vacuum degassing could improve degassing efficiency significantly.

4. Conclusion
(1) Degassing effect of ultrasonic process for high conductivity hard drawn aluminum melt was influenced by ultrasonic power and loading time. The degassing efficiency improved with the increase of ultrasonic power within certain range, stabilizing at 70% with 240W.
(2) Hydrogen content of aluminum melt decreased with the loading time of vacuum degassing process, and was linear with logarithm of vacuum degree.
(3) Results of comparison among ultrasonic, vacuum, vacuum-ultrasonic degassing process for aluminum melt showed that vacuum-ultrasonic process cost much shorter time and presented optimal effect.

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