Wetting of carbon by molten aluminum under ultrasonic field

J T Zhao¹,², Z M Jiang¹,², J W Zhu¹,², S D Zhang¹,² and Y L Li¹,²*

¹ School of Materials Science and Engineering, Northeastern University, Shenyang, Liaoning, 110004, China
² Key Laboratory of Lightweight Structural Materials, Northeastern University, Shenyang, Liaoning, 110819, China
*Corresponding author’s e-mail: liyl@smm.neu.edu.cn

Abstract. Ultrasonic field couple technique has become an effective way to regulate and control the behavior of liquid-solid interface such as wetting, mass transfer and structure in the crossing field of materials science and acoustics. At present, there is no suitable experimental method and technology to systematically study the interfacial behavior regulate and accurately describe the control mechanism of the interfacial structure. In this regard, based on the construction of the "wetting-mass transfer-structural evolution" trinity framework relationship, through the systematic research of the interface behavior of aluminum melt, the experimental method and technology of the interface behavior of aluminum liquid-solid under the ultrasonic field are formed. In this paper, the poor wetting of aluminum and carbon in the preparation of Al-Ti-C grain refiner is investigated. The wetting of aluminum and carbon is improved by the synergistic effect of the ultrasonic field and multifunctional flux K₂TiF₆. The microstructure of aluminum-carbon interface under an optical microscope and scanning electron microscope has been discussed. Meanwhile, the wetting behavior of liquid aluminum on graphite substrate is numerically simulated under ultrasonic field. The results show that the ultrasonic field greatly improves the wetting of aluminum and carbon.

1. Introduction

The liquid-solid interface behavior is a key technology in materials engineering, which determines the possibility of material preparation, the final organizational performance and production efficiency [1]. The main difficulty in producing carbon reinforced aluminum matrix composite and Al-Ti-C grain refiner is that carbon is difficult to be wetting by liquid aluminum [2-4]. The carbon powder was oxidized and the wetting was hindered by the aluminum oxide film, which were the reasons why the poor wetting of aluminum and carbon. P. Baumli and G. Kaptay improved the wetting of the aluminum-carbon interface by multifunctional flux [5, 6]. Multifunctional flux can remove the oxide layer on the surface of liquid aluminum and ensure the formation of TiC layer on the surface of carbon [2]. However, the problem carbon is completely wetted by liquid aluminum can’t be solved by this method.

In the intersection of materials and acoustics, the ultrasonic field technology has become an effective way to control the wetting, reaction, mass transfer and structure of liquid-solid interface [7]. The high density ultrasonic field has the effect of acoustic cavitation and acoustic streaming [8]. Ultrasonic field can be used in the purification, degassing and microstructure refinement of metal melt [9]. Meanwhile, the wetting between the reinforcing phase and the metal melt can be improved, which can affect the migration and motion behavior of the reinforcing phase [10]. In addition, the ultrasonic field enables the particles of the reinforcing phase to obtain external energy, and to release the couluscence state from the
cluster [11]. The above research indicates that adding ultrasonic field to the preparation of carbon reinforced aluminum matrix composites can improve the wetting of aluminum carbon.

In this paper, wetting behavior of the aluminum-carbon interface under ultrasonic field was studied, and the important effect of ultrasonic field on aluminum-carbon wetting was confirmed by combining with the numerical simulation of liquid aluminum wetting on graphite.

2. Experimental

The inside diameter of the graphite crucible is 40 mm and the mass of pure aluminum is 8 g. The surface of pure aluminum was cleaned with alcohol before the experiment. The pure aluminum was heated to 1000 °C in a heating furnace, and then the graphite powder and K₂TiF₆ was put into the crucible under ultrasonic treatment for 20 min. The cross section of the sample was observed by optical microscope and scanning electron microscope. In order to detect the enhancement effect of the ultrasonic field on the aluminum-carbon interface, the wetting and spreading of the aluminum melt on the graphite substrate was simulated under the frequency of 20 kHz.

3. Results

3.1. Metallographic structure

Figure 1(a) shows the metallographic structure of the sample cross section without ultrasonic field. It is obvious that the aluminum-carbon interface is discontinuous. The white needle-like material in the aluminum layer is Al₃Ti. Figure 1(b) shows the Metallographic structure of the sample cross section under ultrasonic field for 20 min. As we can see in the figure 1(b), the aluminum-carbon interface is completely wetting and the interface is tightly bonded. In addition, the Al₃Ti was block-like under the effect of ultrasonic field.

3.2. SEM images

Figure 2 shows the SEM of the sample cross section. As shown in Figure 2(a), there is a crack in the aluminum-carbon interface without ultrasonic field. After ultrasonic field treatment, the aluminum-carbon interface is completely wetting, and the aluminum layer has penetrated into the carbon layer at the interface, as shown in Figure 2(b). It is because that the multifunctional flux K₂TiF₆ can eliminate the oxide film of aluminum, and the Titanium and aluminum form Al₃Ti. Meanwhile, mass transfer is a prerequisite for interface wetting, and the ultrasonic field promotes TiC mass transfer at the interface to make the aluminum-carbon interface wetting.
Figure 3 shows the gas-liquid phase diagram of liquid aluminum and graphite without ultrasonic field and the red part is air and the blue part is liquid aluminum. It can be seen from the figure that there is no obvious change in the spread of liquid aluminum on the graphite and the wetting angle was about $130^\circ$.

Figure 4 shows the gas-liquid phase diagram of liquid aluminum and graphite under ultrasonic field. It is obvious that under the given condition, the liquid aluminum was wetted with graphite under the effect of the ultrasonic field. Liquid aluminum gradually spreads on the graphite substrate from the initial hemisphere. The wetting angle decreased from $130^\circ$ to $15^\circ$, and the wetting effect is greatly improved, which is consistent with the experimental result.
4. Conclusion
The wetting of the aluminum-carbon interface was greatly improved by the combined effect of the ultrasonic field and multifunctional flux K2TiF6. The technical problem of difficult wetting of aluminum-carbon interface is solved, which provides a theoretical basis and technical support for the preparation of carbon reinforced aluminum matrix composite and Al-Ti-C grain refiner.

Acknowledgments
This work was supported by National Natural Science Foundation of China under Grant number 11574043.

References
[1] Ding Z., Hu, Q., Lu, W., Ge, X., Cao, S., Sun, S. (2018) Microstructural evolution and growth behavior of intermetallic compounds at the liquid Al/solid Fe interface by synchrotron X-ray radiography. Mater. Charact., 136: 157–164.
[2] Baumli, P., Sytchev, J., Budai, I., Szabo, J.T., Kaptay, G. (2013) Fabrication of carbon fiber reinforced aluminum matrix composites via a titanium-ion containing flux. Composites: Part A., 44: 47–50.
[3] Calderon, N.R., Voytovych, R., Narciso, J., Eustathopoulos, N. (2010) Wetting dynamics versus interfacial reactivity of AlSi alloys on carbon. J. Mater. Sci., 45: 2150–2156.
[4] Flores-Zamora, M.I., Estrada-Guel, I., González-Hernández, J., Miki-Yoshida, M., Martínez-Sánchez, R. (2007) Aluminum–graphite composite produced by mechanical milling and hot extrusion. J. Alloys. Compd., 434-435: 518–521.
[5] Baumli, P., Sytchev, J., Kaptay, G. (2010) Perfect wettability of carbon by liquid aluminum achieved by a multifunctional flux. J. Mater. Sci., 45: 5177–5190.
[6] Juhasz, K.L., Baumli, P., Sytchev, J., Kaptay, G. (2013) Wettability of graphite by liquid aluminum under molten potassium halide fluxes. J. Mater. Sci., 48: 7679–7685.
[7] Chen, X.R., Ning, F.K., Hou, J., Le, Q.C., Tang, Y. (2018) Dual-frequency ultrasonic treatment on microstructure and mechanical properties of ZK60 magnesium alloy. Ultrason. Sonochem., 40: 433–441.
[8] Puga, H., Barbosa, J., Teixeira, J.C., Prokic, M. (2014) A new approach to ultrasonic degassing to improve the mechanical properties of aluminum alloys. J. Mater. Eng. Perform., 23: 3736–
[9] Sri Harini, R., Nampoothiri, J., Nagasivamuni, B., Raj, B., Ravi, K.R. Ultrasonic assisted grain refinement of Al–Mg alloy using in-situ MgAl2O4 particles. Mater. Lett., 145: 328–331.

[10] Dehnavi, M.R., Niroumand, B., Ashrafizadeh, F., Rohatgi, P.K. (2014) Effects of continuous and discontinuous ultrasonic treatments on mechanical properties and microstructural characteristics of cast Al413–SiCnp nanocomposite. Mater. Sci. Eng. A., 617: 73–83.

[11] Eskin, G.I., Eskin, D.G. (2003) Production of natural and synthesized aluminum-based composite materials with the aid of ultrasonic (cavitation) treatment of the melt. Ultrason. Sonochem., 10: 297–301.