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The periodic breakup layers in vibration-solidified Al-3%Mg alloy

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Based on experimental results, this paper presents that under specific vibration and solidification conditions, there are several periodic breakup layers appearing in the crystallization of Al-3% Mg alloy. The effect of such layers on mechanical properties of the allyoy have been studied.

1. Introduction

In the growth process of dendritical crystal a periodic breakup layers tissue can be produced in the direction of crystal growth under vibration with controlled frequency and amplitude. It is shown by experimented that the formation and distribution of the structure depend on vibration parameters. Under the excitation at low frequency, the formation of the stripe layer chiefly depends on the thermal convection caused by temperature gradient fluctuation. This phenomenon results from the effect of vibration on crystal growth rate, the integrity of the crystal and the condensation of impurities [1]. Under the excitation at high frequency with greater intensity, i.e., at the fundamental resonance frequency, the formation of the bamboo joint is mainly associated with vibration parameters, the formation of excitation, the mechanical properties of solid phase and solid-liquid interface. (including the effect of segregation on the strength of interface).

The periodic breakup layers are the imprints of instant interface patterns preserved in specimen during solidification, hence can be utilized to identify the morphology of the interface.

It is also shown by experiments that the existence of periodic layers affects the mechanical properties (including tensile strength and ductility) of the alloy significantly.

2. Experimental method

The vibration induction solidification system consists of a unidirectional solidifying apparatus, a longitudinal exciting part and a vibration detection analyser as shown in Fig. 1.

The exciting force is picked up by a force transducer (Model 8200 B & K). And the response of the solidification system is detected by an accelerometer (Model 4368 B & K). The characteristics of the signal and the dynamic behavior of the solidification system are processed by a dual-channel real-time analyzer. The frequency response function of solidification system is shown in Fig. 2.

The stable sinusoidal excitation in the frequency range of 0–20 kHz is acted longitudinally on the specimen. The first three resonant frequencies of the solidification system and the relevant responses are listed in Table I.

Using the vibration parameters given in Table I, the excitation is carried out at the first resonant frequency. The solidification system is excited incessantly during the whole solidification process (for more than one hour). The time interval between the end of excitation and quenching is 13.8 sec.

In addition, the temperature distribution of liquid metal at the front of interface is shown in Fig. 3a, where T_L is the temperature of the liquid phase, z is the distance between the origin of the frame of reference and the solid-liquid interface, and G_L is the temperature gradient. Fig. 3b shows the relation between time t and the thickness of solid phase s and R is the growing rate.

3. Periodic layer tissue

Through the experiments metioned above, we found

(1) The periodic bamboo joint structure can be formed under stable sinusoidal excitation at the 1st resonant frequency of the solidification system. The morphology of such structure is shown in Fig. 4. From which one can see that the layers parallel each other and the intervals are nearly identical. The tissue appears in a periodic bamboo-joint pattern along the direction of the crystal growth. Fig. 4 also shows that the layer intervals are affected by vibration intensity. Fig. 5 is the morphology of columnar dendritical crystal under static solidification.

(2) Though the bamboo joint structure appears periodically in space domain, it may not possess periodicity in time domain since it takes varying time to form different layers during solidification.

(3) Under other conditions of excitation, sometimes the breakup occurs obviously between the 1st arm and 2nd arm, sometimes the 2nd arm merged with the 1st one. The former is the grain refinement by longitudinal vibration, while the latter is the increment of the grain size. Under neither of these circumstances, the columnar dendritical crystal structure can't be formed.

(4) Within the interval between layers, the local segregations are three times those in static solidification, and

TABLE I Amplitude of acceleration (m/s^2) at the first three resonant frequencies

	Resonant frequency (Hz)		
L–X(m)	470	1050	1736
0.19	38.39	38.55	32.50
0.17	38.41	38.66	32.78
0.15	38.43	38.77	33.03
0.13	38.45	38.86	33.25
0.11	38.46	38.94	33.43
0.09	38.48	39.01	33.59
0.07	38.49	39.06	33.71
0.05	38.49	39.10	33.81
0.03	38.50	39.13	33.87
0.01	38.50	39.14	33.90
0	38.50	39.14	33.91

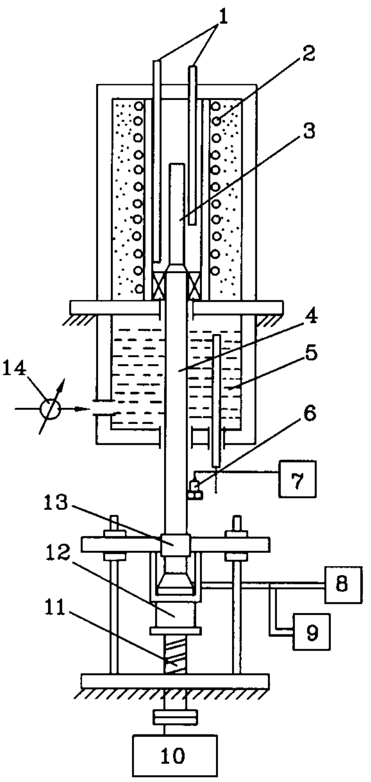


Figure 1 Vibrational Bridgman arrangement. 1, Thermocouple; 2, resistance-heated furnace; 3, crucible; 4, pulldown rod; 5, cooling tank; 6, accelerometer, 7, detecting meter; 8, signal generator; 9, frequency detector, 10, electromotor; 11, screw; 12, electromagnetic vibrator; 13, jig; 14, flowmeter.

far greater than those in other conditions of vibrational solidification.

4. The effect of periodic layers tissue on mechanical properties of alloy

Experiments show that the existence of periodic layers makes the tensile strength and ductility of the dendritical crystals of Al-3% Mg alloy less than those in static solidification, see Fig. 4, the tensile strength is 18.41% and the ductility 45.85% less. The mechanical properties of Al-3% Mg alloy at the first three resonant frequencies are shown in Table II.

TABLE II Values of tensile strength (σ_6) and ductility (δ) of dendritical crystal under vibration

	Static	1st fr	2nd fr	3rd fr
σ_b (MPa)	1.556	1.269	1.750	1.779
δ (%)	15.68	8.49	27.2	30.75

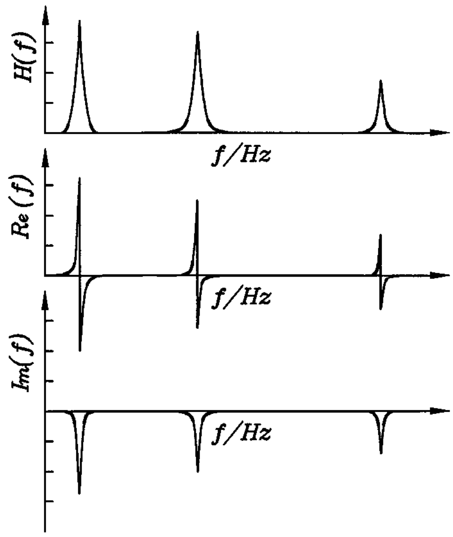
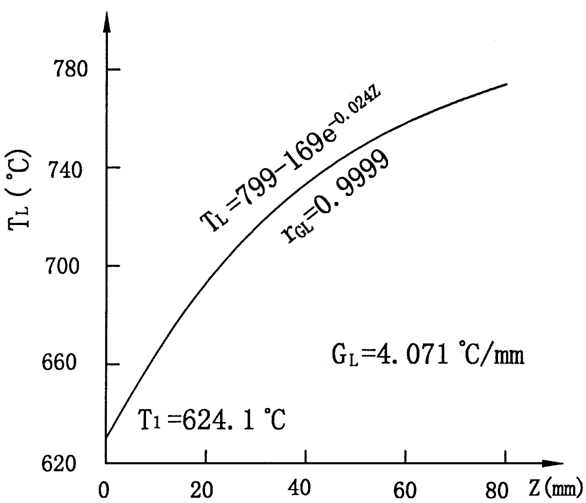
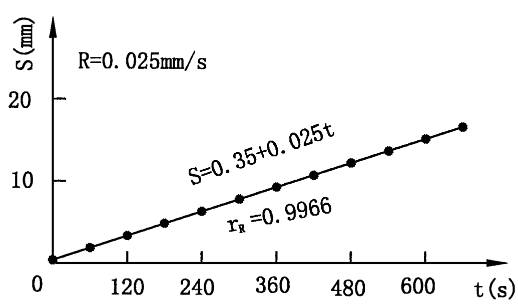


Figure 2 Transfer function of the solidification system.



(a) Temperature distribution of liquid phase



(b) Thickness of solid phase vs. time

Figure 3 Solidification parameters at the 1st resonance.

Figure 4 Morphology of break-up layers tissue.

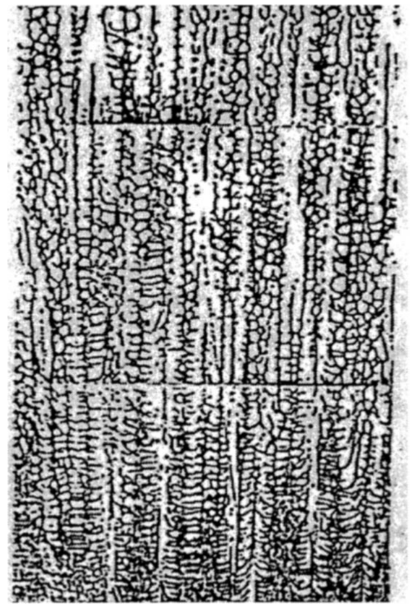


Figure 5 Morphology of static dendritical crystal.

5. Conclusions

(1) Under the stable sinusoidal excitation in the crystal growth direction with certain frequency (the first resonant frequency of solidifying system), intensity and duration, the periodic layers tissue can be formed in the Al-3% Mg alloy dendritical crystal. The morphology characteristics of tissue are as follows: layers parallel each other and the intervals between them are nearly identical.

(2) The mechanism of breakup layers formation under vibration can be explained with the theory of fatigue of the dendritical crystal at the front of interface. According to the theory, the formation of layers chiefly results from resonant frequency, excitation condition and impurity segregation on the interface. The periodic breakup layers formation depends not only on solidification parameters, strength of crystal at interface, but also on vibration parameters (frequency, intensity) and excitation conditions (excitation moment and duration).

(3) The existence of bamboo joint structure affects the mechanical properties of solidified material significantly, such as reduction in tensile strength and ductility.

(4) The periodic bamboo joint structure results from the imprints of the instant solid-liquid interface patterns in the specimen during solidification. Hence, they can be utilized directly to identify the morphology of the interface.

References

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