Theses of Ph.D. dissertation

Ceramic Particles Stabilized Aluminum Foams

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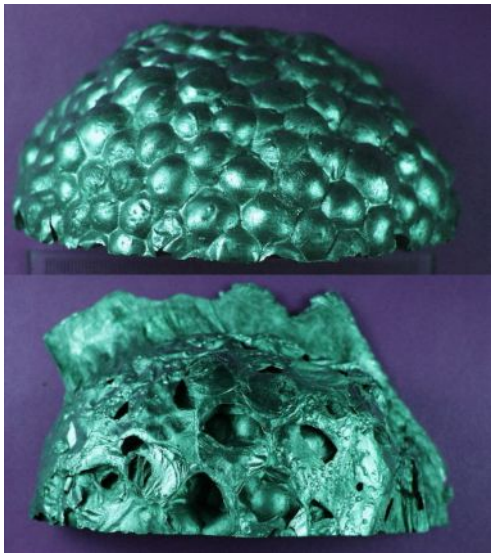

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BACKGROUND AND AIMS

Metal foams belong to the most challenging materials developed recently. A number of manufacturing technologies for foamed metals have been developed, mostly based on empiricism instead on a profound scientific knowledge. Despite their quality improvement in the last 10 years the resulting metal foams still suffer from non-uniformities and other deficiencies.

Metal foams can be characterized by three expressions: profitability, safety and noise reduction. By exclusive combination of gas bubbles and metallic materials one can implement: a) an extra increase of the price of a product, b) new economically important energy absorbing materials increasing safety of the cars and the buildings, c) noise reduction by sound absorption and vibration damping. The volume fraction of gas bubbles in the metal is a simple variable to tailor the properties for the costumer requirements. The wide range of possible properties can lead to innovative applications, which is a strong driving force for the improvement of metal foam production technologies.

Several types of metal foams have been produced since the first one patented in 1948 [1, 2, 3]. In the 1990's it was clarified that direct foaming of metallic melt or the indirect foaming of metal powder compact can produce metal foams cost efficiently. Nearly all metals can be foamed but aluminum has the highest importance. The main challenge of recent research is to achieve a uniform cellular structure, to perfect reproducibility in manufacture and to control foam architecture.

In 2000 D. Leitlmeier and coworkers at LKR, Austria reinvestigated the direct foaming process and successfully developed aluminum foams with homogeneous cell size distribution, now called METCOMB® [4, 5].

The first metal foam from CYMAT® was shown to me by Prof. Bárczy in 1998. At that time my students and I started to learn about aqueous foam stability and heat conductivity of polymeric foams. Under my supervision three student-research works [6, 7, 8] and two diploma works [9, 10] have been executed on aqueous, polymeric and metal foams.

In 2000 and 2001 – as an AMTT user – I carried out measurements of metallic foam heat conductivity and oxide layer examination by TEM at ARC Seibersdorf, Austria. In September 2001 I became the leader of a new "foam stability" project with financial support of LKR, Austria. The project is strongly related to industrial development under a confidentially agreement. Since that time I partly worked in Austria with Prof. Degischer and partly in Miskolc and I had the fortune to experience both the phenomenon (academy) and the purpose (industry) oriented research [11]. The project has been finished by the end of 2002.

In summary I attempted to answer the following questions related to ceramic particle stabilized aluminum foams:

1. What is the apparent surface tension of particle-reinforced aluminum melt?
2. How do the process parameters influence the cell wall structure?
3. What is the effect of the blowing gas?
4. How is this liquid-aluminum foam stabilized?

EXPERIMENTS AND EXAMINATION METHODS

The **materials** selected for investigation can be divided into 5 groups. Pure aluminum alloys without particles, Duralcan metal matrix composites (MMC), further alloyed Duralcan MMCs, MMCs produced by LKR and CYMAT foam. All the MMCs had a wrought or cast aluminum alloy matrix and were reinforced by 10-20 μm size Al_2O_3 or SiC particles.

Differential Scanning **Calorimeter**s were applied to determine the solidus and liquidus temperature of the MMCs. The measurements were carried out in nitrogen atmosphere with 5 K/min heating and cooling rate.

Considering the advantages and disadvantages of various high temperature **surface tension measurement** methods, a self constructed High Temperature Maximum Bubble Pressure Tensiometer (HTMBPT) was built at the University of Miskolc. Apparent surface tension measurements were performed on Al_2O_3 stabilized wrought alloy series and pure aluminum.

Prior to the foaming experiments **single cell wall pull out tests** demonstrated the stability of liquid MMC films and the instabilities of particle-free liquid-aluminum alloys. Aluminum liquid foam was produced in an adiabatic furnace of LKR Austria by gas injection into an MMC melt. The applied **foaming** equipment was constructed for these experiments. Oxygen, air and nitrogen with 3 ppm oxygen were used as foaming gases. Due to the special gas injector the bubble formation was well controlled. After foam production the liquid-metal foam was held isothermally and solidified then in air or quenched in water.

The following **structural examination methods** were applied in order to determine the cell wall geometry and the microstructure of these solid aluminum foams: micrometer, light optical microscopy, scanning electron microscopy, image analysis, x-ray diffraction and transmission electron microscopy.

SCIENTIFIC THESES

1. The **apparent surface tension** of foamable liquid aluminum can be determined applying the self-constructed High Temperature Maximum Bubble Pressure Tensiometer. Increasing Al_2O_3 particle concentration has a decreasing effect on surface tension (Fig. 1).

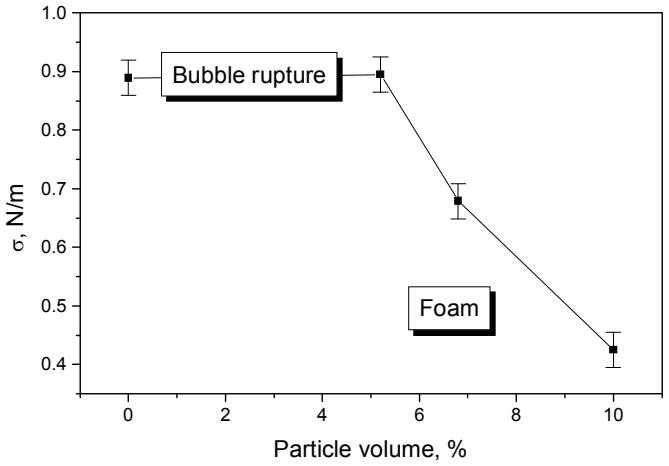

Fig. 1. Surface tension of Al MMCs in function of Al_2O_3 particle content of the melt at 700°C

2. The effect of **process parameters** on the geometrical and microstructure of the Al foams was described. It was shown that at foaming temperature (700°C) Al_2O_3 particles reacted with liquid aluminum (forming spinel) if the Mg content of the alloy was higher than 0.3 at %. High Si content suppressed the spinel formation. The size of the dendrite arms was similar to the particle size in the quenched samples. Thus the observed particle distribution is considered as it was in the liquid. The particle concentration in the cell walls is considerably higher than in the original melt. In the case of foaming by nitrogen the cell wall surfaces are further enriched by particles, whereas surface segregation was not significant foaming with air or oxygen. The lognormal thickness distribution of cell walls was demonstrated by 400 individual thickness measurements on each of the foam samples. The cell wall thicknesses are almost independent of the type of blowing gas but slightly depend on alloying elements and foaming temperature. They are almost twice as thick for Al_2O_3 containing matrixes than for SiC reinforcements: in the range of 100 μm (about 10 times the Al_2O_3 particles' diameter, if spinel was formed at the interface) and 50 μm (about 5 SiC diameters), respectively. There is some evidence that in absence of the interface spinel the cell wall thickness is somewhat smaller. The observed cell wall thickness remained constant even when solidification was delayed. Beyond the characteristic cell wall thickness drainage effects did not occur even after 100 min isothermal holding.

3. Using oxygen containing blowing gas produces **oxide skins** on the cell wall surfaces, which stabilize the foam structure by their mechanical rigidity. The thickness of that oxide skin depends on the foaming gas and the wall material in the way listed in Table 1.

Short-term oxidation mostly produced homogeneous oxide layer, which most probably built up from γ-Al_2O_3 grains. After long-term oxidation primary and secondary oxides are present in the skin.

Table 1. The oxide layer thickness of METCOMB foams measured by TEM

	N_2 foamed AlSi9Mg0.6/ SiC/20p	Air foamed AlSi9Mg0.6/ SiC/20p	O_2 foamed AlSi9Mg0.6/ SiC/20p	O_2 foamed AlSi9Mg1.2/ SiC/20p
Average thickness, nm	12 ± 1	37 ± 6	62 ± 31	28 ± 9

4. The critical parameters influencing **foam stability** of particle-reinforced aluminum melts are summarized: In order to have stable liquid-aluminum foam both a suitable amount (more than 5 vol%) of poor wetting particles and sufficiently thick oxide layer (more than 20 nm) are necessary. Foam stability is directly connected with largely reduced surface tension. Stability is also influenced by technology dependent reaction layers on particles, but nearly independent of the alloy, foaming temperature and time.

UTILIZATION

The results can be used for understanding particle stabilized aluminum foaming and designing higher quality aluminum foams. They have already been applied to improve the models of particle-stabilized foams [12, 13].

OUTLOOK

Further investigation will be carried out:

- Experiments on understanding the role of wettability of particles in liquid foam stability.
- Effect of nanosize particles on foam stability of powder metallurgically produced MMCs.
- In-situ investigation of cell wall thinning and rupture by X-ray radiography.

SCIENTIFIC PUBLICATIONS

Abstracts

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