

# LIGHT METAL COMPOSITES BY USING ALUMINIUM ALLOY APPLICATION –A REVIEW

P.Vignesh<sup>1\*</sup>, P.Senthilkumar<sup>2</sup>, S.Magibalan<sup>3</sup>, K.Perumal<sup>4</sup>, K.Selvaraj<sup>5</sup>

Assistant Professor, Department of Mechanical Engineering, K.S.R College of Engineering, Tiruchengode-637215.

Professor and Head, Department of Mechanical Engineering, K.S.R College of Engineering, Tiruchengode-637215.

Assistant Professor, Department of Mechanical Engineering, K.S.R College of Engineering, Tiruchengode-637215.

Assistant Professor, Department of Mechanical Engineering, K.S.R College of Engineering, Tiruchengode-637215.

Assistant Professor, Department of Mechanical Engineering, K.S.R College of Engineering, Tiruchengode-637215.

**Abstract:** A composite material is a combination of two or more chemically distinct and insoluble phases; its properties and structural performance are superior to those of the constituents acting independently. A continuously metallurgic transition is very important for industrial applications, such as joint structures of space frame constructions in transport industry. In this project, 'compound casting' of light metals is investigated, aiming at weight-saving. The substrate used is a wrought aluminium alloy of type AA5xxx, containing magnesium as main alloying element. The melts are aluminium alloys, containing various alloying elements (Cu, Si, Zn), and magnesium. By replacing the natural oxygen layer with a zinc layer, the inherent wetting difficulties were avoided, and compounds with flawless interfaces were successfully produced (no contraction defects, cracks or oxides). Electron microscopy and EDX investigations as well as optical micrographs of the interfacial areas revealed their continuously metallic constitution. Diffusion of alloying elements leads to heat-treatable microstructures in the vicinity of the joining interfaces in Al–Al couples. This permits significant variability of mechanical properties. Without significantly cutting down on wettability, the formation of low-melting intermetallic phases (Al<sub>3</sub>Mg<sub>2</sub> and Al<sub>12</sub>Mg<sub>17</sub> IMPs) at the interface of Al–Mg couples was avoided by applying a protective coating to the substrate. Various processing techniques for the fabrication of Aluminium matrix composites, testing of their mechanical properties are available.

**Keyword:** Metal matrix

## 1. INTRODUCTION

Metal-matrix composites (MMCs) are engineered combinations of two or more materials (one of which is a metal) where tailored properties are achieved by systematic combinations of different constituents. Lightweight construction in the transport industry helps reduce weight and thus save fuel. To optimize performance, a combination of materials is the most efficient method, because one material alone is often insufficient. Light metals are not easy to join, though. Weak links arise at the joints, such as rivets, welds or brazing connections. Furthermore, the natural oxide layer on aluminium, for example, is thermodynamically stable and inert, has a melting point much higher than the bulk material, and is not easily wettable by metallic melts.

If a metallic melt is cast onto or around a solid metal shape, forming a diffusion reaction zone and thus a continuous metallic transition, one talks about compound casting[1]. A prerequisite is the formation of zones where the cast alloy's components diffuse into the solid material, partly via the formation of solid solutions and partly via the formation of intermetallic phases. If the aluminium oxide layer remains on the substrate's surface it will persist during the casting procedure and inhibit the formation of the continuous metallic junction needed for a 'compound cast' part. The present work focuses on eliminating the oxide layer and the development of a coating which will inhibit repassivation and thus make the aluminium substrate's surface wettable by metallic melts[2]. Light metal couples (Al–Al and Al–Mg) were produced by compound casting on laboratory scale.

## 2. LIQUID STATE FABRICATION OF METAL MATRIX COMPOSITES

### 2.1 Substrate coatings

One very efficient way to remove the natural oxide layer from aluminium and to prevent its formation after the treatment is the application of the so-called zincate process[3–6]. It replaces the Al<sub>2</sub>O<sub>3</sub> layer with a metallic Zn film with a thickness of several hundred nanometers, via two parallel chemical reactions[2,4,7]. First, the oxide layer is removed by etching, while metallic Al oxidizes and dissolves, Zn anions are reduced and deposit as a dense metallic layer in the second reaction[8]. The solution used in this work was a single solution containing NaOH and Zn anions, and was applied in ambient conditions. Prior to immersion in this zincate solution, the substrate had to be pre-treated. As the substrate was received in rolled condition, the outermost microns ('rolling layers') had to be removed. The samples were thus cleaned in a mild pickle solution at 55°C to remove carbon contaminations, and subsequently the aluminium oxide layer was etched away in a strong alkaline NaOH solution (pH > 13) for 2 min at 55°C. The pickling layer, which was built up during this process, was removed by etching in 35% nitric acid. Between each of these important cleaning processes, the samples were rinsed in deionized water for 2 min. This zincate treatment removed the aluminium oxide layer permanently, but did not yet yield the good wetting properties needed for successful compound casting. For Al–Al compound casting, the coating thickness was increased to 10 μm via zinc galvanizing. For Al–Mg compounds, another coating had to be applied to prevent the excessive formation of brittle intermetallic phases. Manganese was chosen for this purpose, and a 5-μm thick Mn layer was deposited via galvanizing[9].

### 2.2 Wetting experiments

Aluminium-based alloy AlMg1 (AA5005; 1.0 Mg, 0.4 Fe, 0.25 Si, 0.15 Mn—all in mass-%) platelets of 20 mm × 10 mm × 2 mm were used as substrate for wetting experiments. The melts for Al–Al compounds were pure 99.98%-aluminium (Al), aluminium alloys with 7mass-% Si (AlSi7), 7 mass-% Cu (AlCu7) and 7mass-% Zn (AlZn7), respectively. For Al–Mg, only pure 99.98%-magnesium was used. The setup for wetting experiments comprises a horizontal furnace with a device designed both to drop metallic melts onto a substrate and to break and shear the oxide hull off the molten metal. For this purpose, a quartz glass tube with a diameter of 6 mm was narrowed at one end. 300 mg of the alloy was melted inside this tube, and pushed out using a plunger. Upon dropping onto the substrate's surface, none of the

oxide layer de-bris from the melt was present at the interface, and the sample was immediately pulled out of the heated area to cool down. The atmosphere was Ar6 (99.9999% Ar, with previous evacuation to at least  $5 \times 10^{-5}$  mbar), with a furnace temperature of 700°C. This setup was used for all the materials described here.

### 2.3 Heat treatment procedures and diffusion simulations for Al–Al couples

To determine diffusion zone dimensions and the degree of interdiffusion of alloying elements experimentally, Al–Al couples were heat treated and the interface's mechanical properties were investigated. According to the industry heat treatments, T5 and T6 states (without and with solution annealing before artificial ageing, respectively) were established for the interface compositions, where heat treatable compositions formed after sample production. In Table 1, these heat treatments are listed. The ageing temperatures and times varied for each couple composition according to treatments for commercial alloys with similar compositions[10].

Diffusion zone extensions, and thus the area of expected hardness increase, were verified by one-dimensional diffusion simulations. These were performed using DICTRA software[11], with thermodynamic data taken from COST II and aluminium alloys' mobility databases[12,13]. For solidification simulations, starting temperatures were chosen to lie below the solidus of the substrate and above the liquidus of the melts. It was not possible to perform simulations with AlMg1/Al99.98% couples, as the substrate's solidus is lower than the liquidus of Al. A cooling rate of 1 K/s was used for casting simulations, and solution annealing simulations were performed with 500°C for 30 min. A planar solidification front, no significant influence of convection and the presence of only fcc and liquid phases were the simplifying assumptions made.

## 3. LITERATURE REVIEW

This review is based on materials in the Abbey Publications library and files, and includes citations from annotated bibliographies on the shelves. It is not exhaustive, but it may be useful because it is interdisciplinary (drawing upon the literature of conservation as well as papermaking), international, and up to date.

**Banik, Gerhard and Johann Ponahlo, 1981.** "Some Aspects Concerning Degradation Phenomena of Paper Caused by Green Copper Containing Pigments." Preprints, ICOM [International Council of Museums] Committee for Conservation, Graphic and Photographic Documents Working Group, Ottawa, 1981. Paper # 81/14/1, pp. 1-14. 15 refs.

Ten kinds of copper compounds were aged with dry heat and with light, and the degradation products analyzed with infrared spectroscopy. The compounds reacted differently to cellulose. General oxidation processes were not seen as responsible for damaging effects caused by natural aging.

**Bicchiere, Marina, 1996.** "Ferric and Cupric Ions: Interactions with Cellulose as a Function of pH." Paper presented at the International Conference on Conservation and Restoration of Archive and Library Materials, Erice, Italy, April 1996. Pp. 599-609 in the Preprints.

Two mechanisms have been proposed for the cellulose-metal interaction: a free radical mechanism in which the metal catalyzes homolytic scission of the cellulose peroxide, and a Lewis mechanism. In a low acid medium, iron ions catalyze the cleavage of the cellulose 1-4-b-glucosidic bond, whereas copper ions catalyze the oxidation on the anhydroglucose ring. Results are in agreement with the Lewis mechanism. In low-alkaline medium, both metallic ions seem to be active on the cleavage of the glucosidic bond. Reducing compounds are being investigated to find one that can impede oxidation catalyzed by metals and also bleach the paper.

**Farber, Eduard, 1954.** "Chemical Deterioration of Wood in the Presence of Iron," *Industrial and Engineering Chemistry* 46/9, p. 1968-1972. There is a definite reduction in mechanical strength, carbohydrate content and lignin solubility after wood has been exposed to moisture and air in contact with iron. (This was a study of old railroad ties.)

**Harrison, James E., 1989.** "Ferric Iron in Mill Water can Affect Paper Brightness," *American Papermaker*, Nov. 1989, p. 33. TAPPI water quality standards for turbidity, color, iron and manganese are summarized for fine paper, bleached kraft, unbleached kraft, groundwood kraft and soda and sulfate pulp in a little table, which by the way does not say what the units of measurement are. A graph from TAPPI February 1982 is reproduced here, showing how G.E. brightness falls when pulp contains more than 0.01% of iron.

**Iversen, Tommy, 1989.** "Oxidative Decomposition of the Polysaccharide Components of the Paper," in *Ageing/ Degradation of Paper: A Literature Survey*, p. 43-47. (FoU-projektet för papperskonservering, Report No. 1E) [Riksarkivet], Stockholm, Sept. 1989. ISSN 0284-5636. "During the hydrolytic degradation of cellulose, new low molecular products... are formed which can increase the paper's sensitivity to oxidation. This means that the oxidation breakdown of paper can have a greater importance the farther the hydrolytic ageing process has reached.... The autoxidation, however, also introduces acid carboxyl groups into the different components of the paper, which means that oxidation can accelerate the hydrolytic degradation of the cellulose."

**Jhuang, Jenfeng and Christopher J. Biermann, 1993.** "Rosin Soap Sizing with Ferric and Ferrous Ions as Mordants," *Tappi Journal* Dec. 1993, p. 141-147. The authors hypothesize that iron ions are effective mordants only in the sizing of lignin-rich unbleached pulps. For this use iron is much better than alum. Iron ions are recommended for sizing of dark unbleached or mechanical pulp papers [where presumably the darkening caused by the iron will not be noticed].

**Kolar, Jana, and Gabrijela Novak, 1996.** At the International Symposium on Book and Paper Conservation in Ljubljana, Slovenia, these authors will present their paper entitled "Investigation of the Effect of Various Metal Ions on Ageing Stability of Cellulose." Proceedings will be published. For information contact Ms. Jedert Vodopivec, Arhiv Republike Slovenije, fax (386 61) 216 551.

**Lindström, Tom, 1989.** "Effect of Metal Ions." Pp. 108-111 in *Ageing/Degradation of Paper: A Literature Survey*. (FoU-projektet för papperskonservering, Report No. 1E) This is a compact review of the ways in which metals can affect cellulose. Metal hydroxides/oxides catalyze cellulose hydrolysis, even in the absence of oxygen, especially at high temperatures. In an earlier chapter (p. 67-70) he points out the fact that Fe, Cu and Mn strongly accelerate the absorption of SO<sub>2</sub> and SO<sub>3</sub> in paper.

**Neevel, J.G., 1995.** "The Development of a New Conservation Treatment for Ink Corrosion, Based on the Natural Anti-oxidant Phytate." Paper presented at the September 1995 meeting of IADA in Tübingen, and printed on p. 95-100 of the Preprints (edited by Mogens S. Koch and K. Jonas Palm, published by the Royal Danish Academy of Fine Arts in Copenhagen; ISBN 87 89730-19-4). The author is at the Central Research Laboratory in Amsterdam.

During accelerated aging, deacidification failed to protect the paper against new acidity; therefore, acidity cannot be the only cause of ink corrosion. In simulated ink corrosion tests, lignin-free paper degraded faster than the lignin-containing paper, even when it was sized with acid alum. Lignin acts as an anti-oxidant because it is oxidized faster than cellulose and forms stable radicals; this shows that the process is oxidative. Iron II ions are seen as catalysts. Attempts to prevent oxidation by use of EDTA only accelerated the degradation process. Only a few complexing agents block the Fenton reaction (formation of hydroxyl radicals); one of them is phytic acid, found in

seeds. Neevel's report is detailed and well-presented. The research was also reported in *Restaurator*, 1995, v.16, p. 143-160, with 45 references.

**Shahani, Chandru J. and Frank H. Hengemihle.** "Effect of Some Deacidification Agents on Copper-Catalyzed Degradation of Paper." Distributed as a separate by the Preservation Directorate, Library of Congress, November 1995 (Preservation Research and Testing Series No. 9501). 13 pp. Originally presented at the conference on Conservation of Historic and Artistic Works on Paper, organized by the Canadian Conservation Institute, Ottawa, Canada, Oct. 3-7, 1988, where it appeared in the program as "The Effect of Deacidification on the Aging of Paper Contaminated with Copper"; however, it did not appear in the postprints.

Aqueous solutions containing magnesium, calcium (in the Barrow two-step process, after CaOH) and zinc bicarbonate were used to deacidify copper-doped paper, in an effort to find the cause and control of corrosion by copper-based pigments. The work revealed the reason for the effectiveness of magnesium bicarbonate and the relative ineffectiveness of the Barrow two-step treatment in inhibiting the catalytic effect of copper on the oxidative degradation of paper. A simple qualitative test demonstrated that complexation of the adsorbed copper is indeed the key to its removal from the paper, but the complexation effect takes place with bicarbonate ions rather than with magnesium species. Unlike free copper ions, the soluble bicarbonate complex of copper has little affinity for sorption sites on the cellulose matrix; possibly some of the adsorbed copper can be washed out. But if the paper was treated first with calcium hydroxide, subsequent bicarbonate treatment was ineffective.

**Shahani, C.J. and F.H. Hengemihle, 1986.** "Influence of Copper and Iron on Permanence of Paper." *Historic Textile and Paper Materials: Conservation and Characterization*. (Advances in Chemistry Series No. 212; ACS, Aug. 27-29, 1984). p. 387-410. Neutralization of bleached kraft paper slowed the degradation rate, decreasing Fe-catalyzed degradation but increasing the efficiency of Cu-catalyzed degradation. The effect of chelation was also studied.

**Williams, John C., C.S. Fowler, M.S. Lyon, and T.L. Merrill, 1977.** "Metallic Catalysts in the Oxidative Degradation of Paper." *Advances in Chemistry Series, ACS #164*, p. 37-61. Even alkaline buffered paper can fail by oxidative degradation if it contains transition metal catalysts (compounds of copper, cobalt, or iron). Magnesium carbonate offers better protection against aging than calcium carbonate. Paper was treated with copper acetate at various pH levels and oven aged. Folding endurance declined more in the humid oven than in the dry oven, indicating that dry-oven aging has little predictive value for oxidate degradation.

**Wilson, L.P., 1920.** "Catalytic Action in the Oxidation of Cellulose." *Journal of the Society of [the?] Chemical Industry*, [Transactions, 39 #13, July 15, 1920]. [No page number.] In the viscose process, by which rayon is made, cellulose is gelatinized by oxidizing it in caustic soda, with the aid of catalysts, which are usually oxides or hydroxides of metal which exist in two states of oxidation, e.g., iron, nickel, cobalt, cerium, vanadium or manganese.

## CONCLUSION

This paper presents the different combination of reinforcements used in the synthesis of hybrid AMCs and how it influences its performance. Compound casting of various light metals was investigated on a laboratory scale. Through adequate surface treatments and coatings, the AlMg1 substrate's wettability was improved in a way that the couples of Al-Al and Al-Mg were successfully produced. Interfaces showed very low (Al-Mg) to no (Al-Al) formation of IMPs, and other defects, such as oxide inclusions, contraction cavities or cracks. The combined coating of zincate treatment and electrolytically deposited zinc for Al-Al compounds offers major advantages compared to other approaches to joining light metals. Zones with heat-treatable compositions were formed in regions ranging up to 200  $\mu\text{m}$  to both sides of the interface, which could be quantified by microhardness indents after heat-treatment procedures. Mechanical properties of the interfacial area can thus be adapted to the field of a future component's application. DICTRA simulations yielded diffusion zone dimensions of about 50–200  $\mu\text{m}$ , which coincides well with the experimental findings, and can help to reduce the volume of future wetting experiments with other alloys.

## REFERENCE

- [1] Banik, Gerhard and Johann Ponahlo, 1981. "Some Aspects Concerning Degradation Phenomena of Paper Caused by Green Copper Containing Pigments." Preprints, ICOM [International Council of Museums] Committee for Conservation, Graphic and Photographic Documents Working Group, Ottawa, 1981. Paper # 81/14/1, pp. 1-14. 15 refs.
- [2] Bicchieri, Marina, 1996. "Ferric and Cupric Ions: Interactions with Cellulose as a Function of pH." Paper presented at the International Conference on Conservation and Restoration of Archive and Library Materials, Erice, Italy, April 1996. Pp. 599-609 in the Preprints.
- [3] Farber, Eduard, 1954. "Chemical Deterioration of Wood in the Presence of Iron," *Industrial and Engineering Chemistry* 46/9, p. 1968-1972.
- [4] Harrison, James E., 1989. "Ferric Iron in Mill Water can Affect Paper Brightness," *American Papermaker*, Nov. 1989, p. 33.
- [5] Iversen, Tommy, 1989. "Oxidative Decomposition of the Polysaccharide Components of the Paper," in *Ageing/ Degradation of Paper: A Literature Survey*, p. 43-47. (FoU-projektet för papperskonservering, Report No. 1E) [Riksarkivet], Stockholm, Sept. 1989. ISSN 0284-5636.
- [6] Jhuang, Jenfeng and Christopher J. Biermann, 1993. "Rosin Soap Sizing with Ferric and Ferrous Ions as Mordants," *Tappi Journal* Dec. 1993, p. 141-147.
- [7] Kolar, Jana, and Gabrijela Novak, 1996. At the International Symposium on Book and Paper Conservation in Ljubljana, Slovenia, Proceedings will be published. For information contact Ms. Jedert Vodopivec, Arhiv Republike Slovenije, fax (386 61) 216 551.
- [8] Lindström, Tom, 1989. "Effect of Metal Ions." Pp. 108-111 in *Ageing/Degradation of Paper: A Literature Survey*. (FoU-projektet för papperskonservering, Report No. 1E)
- [9] Neevel, J.G., 1995. "The Development of a New Conservation Treatment for Ink Corrosion, Based on the Natural Anti-oxidant Phytate." p. 95-100 of the Preprints (edited by Mogens S. Koch and K. Jonas Palm, published by the Royal Danish Academy of Fine Arts in Copenhagen; ISBN 87 89730-19-4).
- [10] Shahani, Chandru J. and Frank H. Hengemihle. Library of Congress, November 1995 (Preservation Research and Testing Series No. 9501). 13 pp.
- [11] Williams, John C., C.S. Fowler, M.S. Lyon, and T.L. Merrill, 1977. "Metallic Catalysts in the Oxidative Degradation of Paper." *Advances in Chemistry Series, ACS #164*, p. 37-61.
- [12] Wilson, L.P., 1920. "Catalytic Action in the Oxidation of Cellulose." *Journal of the Society of [the?] Chemical Industry*, [Transactions, 39 #13, July 15, 1920]. [No page number.]