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ALUMINIUM MATRIX COMPOSITES – AN OVERVIEW ON THE MATERIALS SUBSTITUTION AND EFFICIENT USE OF MATERIALS

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Abstract: Development of metal matrix composites has been an important innovation in materials engineering over the past decades. Metal matrix composites offer several attractive advantages over traditional engineering materials due to their superior properties. Therefore, the metal matrix composite become economical alternatives to the monolithic alloys due to their improved specific strength, stiffness and wear resistance combined with better physical properties such as low density and low coefficient of thermal expansion. Materials substitution significantly affects the trend toward more efficient use of monolithic materials. The increasing use of alternative materials in aircraft, automotive and construction applications has motivated the metal industry to provide lighter weight aluminium alloys and metal matrix composites. This paper presents an overview of aluminium matrix composite systems on aspects relating to processing of matrix from re–melted aluminium wastes.
Keywords: metal matrix composites, aluminium matrix, re–melted aluminium wastes

INTRODUCTORY NOTES

Metal matrix composites (MMCs), as the name suggests, consist of fibres or particles surrounded by a matrix of metal. The use of a metal matrix offers the potential of producing a composite with very high stiffness and strength as well as very high temperature resistance.

The aim involved in designing metal matrix composite materials is to combine the desirable attributes of metal and ceramics. The addition of high strength, high modulus refractory particles to a ductile metal matrix produce a material whose mechanical properties are intermediate between the matrix alloy and ceramic reinforcement. Metals have a useful combination of properties such as high strength, ductility and high temperature resistance but sometimes have low stiffness, whereas ceramics are stiff and strong though brittle.

Metal matrix composites (MMCs) comprise a relatively wide range of materials defined by the metal matrix, reinforcement type, and reinforcement geometry. In the area of the matrix, most metallic systems have been explored for use in metal matrix composites, including Aluminium (Al), Magnesium (Mg), Titan (Ti), Iron (Fe), Nickel (Ni), and Copper (Cu). Among metallic matrices, aluminium based matrix remains the most explored metal matrix material for the development of MMCs. This is primarily due to the broad spectrum of properties offered by aluminium-based matrix composites at low processing cost.

From a reinforcement perspective, the materials used are typically ceramics since they provide a very desirable combination of strength and relatively low density. Candidate reinforcement materials include SiC, Al_2O_3, B_4C, TiC, TiB_2, graphite, and a number of other ceramics. In addition, there has been work on metallic materials as reinforcements, notably Wolfram (W) and steel fibers.

Silicon Carbide (SiC) particle reinforced aluminium composites have received more commercial attention than other kinds of MMCs due to their high mechanical properties, wear resistance, low coefficient of thermal expansion and high thermal conductivity. They are remeltable and that can be produced by large quantities by the process analogue to that used for commercial aluminium alloys at cheap cost. Therefore they are more competitive on the MMC market and find wider application in industries.

The morphology of the reinforcement material is another variable of importance in metal matrix composites. The three major classes of reinforcement morphology are continuous fiber, chopped fiber or whisker, and particulate. Metal matrix composites can be classed as having either continuous or discontinuous fiber reinforcement. Discontinuous reinforced MMCs appear to offer more potential due to their ease of manufacture.

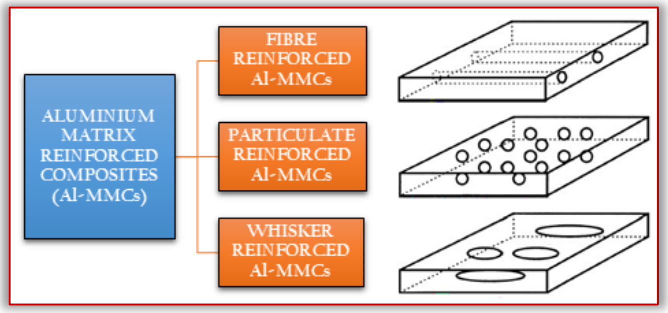

Figure 1. Types of aluminium-based matrix composites

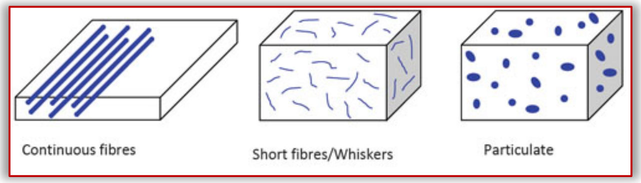

Figure 2. Types of reinforcements

Typically selection of the reinforcement morphology is determined by the desired property/cost combination. Generally, continuous fiber reinforced MMCs provide the highest properties in the direction of the fiber orientation but are the most expensive.

Chopped fiber and whisker reinforced materials can produce significant property improvements in the plane or direction of their orientation, at somewhat lower cost. Particulates provide a comparatively more moderate but isotropic increase in properties and are typically available at the lowest cost. Particle reinforcing in composites is a less effective means of strengthening than fiber reinforcement. The principal advantage of particle reinforced composites is their low cost and ease of production and forming.

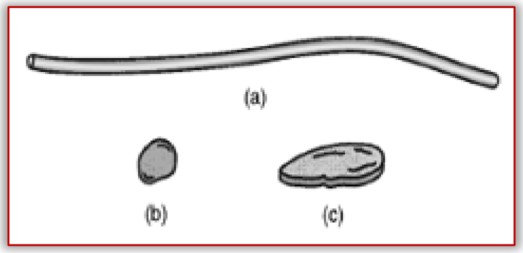

Figure 3. Possible shapes of the reinforced phases in a composite materials: long fiber (aligned continuous, aligned discontinuous, random), (b) particle (spherical, cubic or platelets), and (c) short fiber (whiskers) or flake

By adding to the three variables of metallic matrix, reinforcement material, and reinforcement morphology, the further options of reinforcement volume fraction, orientation, and matrix alloy composition and heat treatment, it is apparent that there is a very wide range of available material combinations and resultant properties.

Most of the studies worked on the specifics of the MMC systems and their components, their manufacturing processes, and their properties, not on the aspects on the materials substitution which significantly affects the trend toward more efficient use of monolithic materials. The technical difficulties associated with attaining a uniform distribution of reinforcement and good wettability between substances are the main research directions.

Combining high specific strength with good corrosion resistance, metal matrix composites (MMCs) are materials that are attractive for a large range of engineering applications. Given the factors of reinforcement type, form, and quantity, which can be varied, in addition to matrix characteristics, the composites have a huge potential for being tailored for particular applications. One factor that, to date, has restricted the widespread use of MMCs has been their relatively high cost. This is mostly related to the expensive processing techniques used currently to produce high quality composites.

ABOUT THE BEVERAGE CANS AND THEIR RECYCLING

Beverage cans today are among the lightest beverage packages. As metal is a permanent material, it has excellent environmental credentials. Drink cans (or beverage can) are often used for beer, cider and energy drinks.

Cans which have been used and discarded by consumers can also be reused, and as mentioned above, recycled material makes up a significant percentage of the aluminium used for beverage cans. The savings from recycling are quite significant to the industry. Beverage cans are fully and infinitely recyclable without loss of quality. Because they are infinitely recyclable, metals are a permanent resource.

Figure 4. Recycling aluminium beverage cans – concept

The raw material of the drink cans (or beverage can) is aluminium (75% of worldwide production). The aluminium base, for beverage cans consists mostly of aluminium, but it contains small amounts of other metals as well. These are typically 1% Magnesium, 1% Manganese, 0.4% Iron, 0.2% Silicon, and 0.15% Copper.

Figure 5. Aluminium beverage can

Aluminium is one of the most cost-effective materials to recycle. When recycled without other metals being mixed in, the can–lid combination is perfect for producing new stock for the main part of the can. The loss of magnesium during melting is made up for by the high magnesium content of the lid.

Figure 6. Beverage can lids

The lid is made of a slightly different alloy than the aluminium for the base and sides of the can. The flat lid must be stiffer and stronger than the base, so it is made of aluminium with more magnesium and less manganese than the rest of the can. This results in stronger metal, and the lid is considerably thicker than the walls.

ALUMINIUM PACKAGING SCRAP SOURCES

Worldwide production of aluminium beverage cans is steadily increasing, growing by several billion cans a year. In the face of this rising demand, the future of the beverage can seems to lie in designs that save money and materials.

Recycled aluminium has become an increasingly important component of metal supply for which effective and efficient technology is needed. The alloy compatibility of the components of the beverage can makes it uniquely suitable for the closed-loop recycling concept and is responsible for the consistently high value of used beverage cans.

Packaging, representing the second largest source of aluminium scrap at global level, deserves a key role in the transition towards the circular economy. The recycling rate of aluminium cans is higher than any other used packaging material. Different aluminium packaging scrap sources were considered:

- mixed packaging aluminium scrap, and
- used beverage can scrap.

Figure 7. Mixed packaging aluminium scrap

Figure 8. Collected used beverage can scrap

To further improve the performances of the aluminium beverage can sector towards circular economy implementation the key actions are:

- to reduce the weight of the lid,
- to develop methods to separate the body and lid at the point of collection, and
- to investigate the potentials of a closed supply chain loop for aluminium cans in terms of combined environmental and economic value creation.

Aluminium cans are recycled over and over again in a true "closed loop" recycling process. But they can typically "up-cycled" into products like MMCs matrix material. Reflecting an increased interest in eco-friendly products, particularly ones that are priced at an affordable level and proving profitable for the manufacturers, the up-cycling can be profitable in the case of MMCs matrix material too. Therefore, recycling of used aluminium beverage cans into MMCs matrix material – in terms of combined environmental and economic value creation – has been tried as a favourable aluminium product recycling method.

Figure 9. Aluminium cans recycling – concept

Up-cycling, also known as creative reuse, is the process of transforming by-products, waste materials, useless, or unwanted products into new materials or products of better quality or for better environmental value. The goal of up-cycling is to prevent wasting potentially useful materials by making use of existing ones. This reduces the consumption of new raw materials when creating new products.

Up-cycling is the opposite of down-cycling, which is the other half of the recycling process. Down-cycling involves converting materials and products into new materials of lesser quality. Most recycling involves converting or extracting useful materials from a product and creating a different product or material.

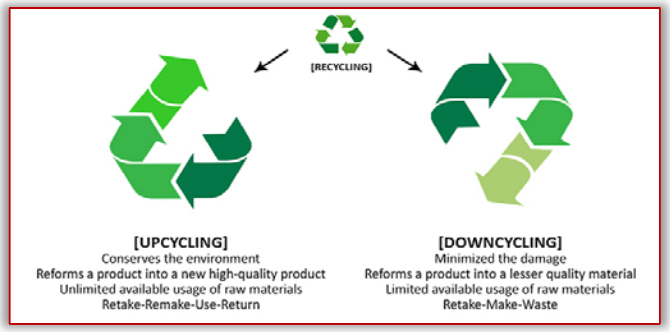

Figure 10. Up-cycling – concept

Aluminium cans are the most sustainable beverage package and are infinitely recyclable. As the most valuable package, aluminium cans are, by far, the most recycled beverage container. Empty cans have the highest economic value of all packaging materials and demand for secondary metal far exceeds the supply. Recycling is an essential part of metal packaging's life cycle. Overall, cans represent a perfect example of truly recyclable packaging and a product that fits a circular economy model very well.

Unlike the can recyclers, who are totally dedicated to a single product of aluminium alloys, automotive recyclers must deal with a number of different alloys with different destinations and relatively low values.

Under these circumstances, no extra purification steps would be required before the aluminium is recycled into high-performance products. This would allow development of new alloy options for potential direct use in new added values components.

CONCLUDING REMARKS

In recent years, the demands for light-weight structural materials with high specific strength to weight ratio and recyclability have increased dramatically in the automotive industry. Aluminium and its alloys are potential candidates to meet the above mentioned requirements.

Demand for lightweight materials in the automotive, aerospace, construction and other related industries has increased in recent years due to environmental concerns, government regulations and consumer demand. Lightweight metal alloys are the preferred choice of these industries due to their low density and high specific strength, as well as other attractive features such as corrosion resistance, dimensional stability, etc. Lightweight metal alloys are widely considered nowadays for their functionality and aesthetics.

As for reinforcement materials, research objectives for MMCs were mainly focused on continuous fiber reinforcement in the early stages MMCs development. However, because of the complex manufacturing process and the relatively high cost of fibrous MMCs, more and more studies have been focused on using discontinuous particles as a reinforcement. With a high melting point, high hardness, and thermal stability ceramic particles such as SiC, have been widely utilized as reinforcements.

With recent advances in the relevant manufacturing technologies, production of these tailor compound materials has become feasible at low cost.

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Note

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