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Materials Today: Proceedings 2 (2015) 3032 – 3041

4th International Conference on Materials Processing and Characterization

Advanced Aluminium Matrix Composites: The Critical Need of Automotive and Aerospace Engineering Fields

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Abstract

The applications of aluminium matrix composite materials are growing continuously in the field of automotive and aerospace because of their superior physical, mechanical and tribological properties as compared to base alloy. Composite materials with metal matrix material e.g. aluminium or magnesium are finding broad level applications in many industries because of their lower density, better wear and corrosion resistance, high strength to weight ratio, good formability, high hardness, high thermal shock resistance, high modulus, high fatigue strength etc. In automotive industry they are being used in various parts e.g. pistons, cylinders, engine blocks, brakes etc. Aluminium based composites reinforced with micro/nano SiC, Al_2O_3, B_4C, TiB_2, ZrO_2, SiO_2 and graphite particles, changes the micro-structural characteristics that develop superior mechanical and physical properties appropriate for automotive/aerospace applications.

Keywords: Aluminium matrix composites; automotive applications; Aerospace applications; Mechanical properties.

1. Introduction

Aerospace systems and automobiles with improved performance require materials with enhanced characteristics such as high strength, temperature withstanding capability, fretting wear resistance, ductility, fracture toughness, fatigue resistance etc. must be as high as possible, while other parameters such as density and cost must be minimized; the latter is of general concern for automobile application and relatively inexpensive light aircraft [1].

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doi:10.1016/j.matpr.2015.07.290

Abrasive wear resistance [2] of 2014 and 6061 Al-based composites may be controllably transformed by thermal ageing. Maximum wear resistance is developed when the composites are in the peak-aged condition, when the aluminium alloy contained a large number of disjointed precipitates. Automobiles have been rapidly multiplied all over the world in last decades. A large number of vehicles have brought serious problems to the mankind such as environmental pollution and large consumption of global energy and resources. An automobile has thousands of components that are made of metals, plastics, ceramics, composites, fluids and additional materials. Automotive tribology spans areas including the ubiquitous squeaking of windshield wipers, the protective function of tribofilms generated by engine oils, and the tribology of metal forming [3, 4]. Automobile industry is making consistent effort to design and produce smaller, lighter and more space/fuel efficient vehicles [5].

It was studied that effect of SiC particulate volume fraction and particle size on the fatigue behaviour of 2080 Al and found that increasing volume and decreasing particle size resulted in an increase in fatigue resistance [6]. P/M technology for sintered iron-based valve seats and valve guides was used and wear resistance was enhanced by the inclusion of copper and phosphorus to form hard inter-metallic phases. A new type of sintered valve seat material in which 6% of calcium fluoride particles had been added to act as solid lubricant and this material in LPG engines replacing lead infiltrated PM alloy [7]. One study reported that sintered aluminium are attractive materials for the automobile industry, both because of low specific gravity and high strength-to-weight ratio of aluminium itself, and the fabrication compensations coupled with powder metallurgy process [8]. Al-SiC composites cams with different compositions (i.e. 10, 20, 25, 30 wt% of SiC) were manufacture and properties were measured. The results shown that the modulus of elasticity, yield strength, compressive strength, hardness, UTS improved while ductility decreased with increase in reinforcement content [9]. Aluminium based composites were reported the most frequently used ones and with possibilities of their use for manufacturing of the tribo-mechanical components and Al-SiCp composite for the production of cam, poppet valve guides and valve seat inserts by the use of powder metallurgy and liquid metallurgy techniques [10, 11]. In one study, the versatility of reaction-processed silica-based composites processed in liquid aluminium has been reported with the the importance of SiC to improve thermal conductivity and changing the metal phase to provide modest high-temperature properties [12]. An engine piston of Al7075has been fabricated with strength comparable to many steels and has good fatigue strength and average machinability. In fatigue analysis, with applied load of 10,000 cycles it gives a high total life. Linear static analysis of piston satisfied all stress and strain conditions and the design was suggested for engines in 2 wheeler segment [13, 14].

Aluminium based metal matrix composites to be used in aluminium graphite pistons and liners and were tested in gas and diesel engines and in racing cars. Lead free aluminium as the substitute for copper-lead bearings used in crank shaft main bearing. 10.0 vol% of 50 nm Al_2O_3 to aluminium gives yield strength 515 MPa by the powder metallurgy process is a substitute for a connecting rod. Replacing components such as A/C pump brackets, timing belts/chain covers, alternator housings, transmission housings, valve covers and intake manifolds with aluminium fly ash components can reduce vehicle cost and weight, thereby reducing emissions and energy [15]. Usage of components made of Aluminium Metal Matrix composites at high temperatures like aerospace and automobile applications, a thermal barrier coating of PSZ, Super-Z alloy, Zirconia Toughened Alumina (ZTA) Alumina-Titania (Al_2O_3 + TiO_2) and Alumina could be plasma sprayed to impart maximum thermal resistance and thermal fatigue resistance to the components.

2. Characteristics of Composite Materials

The nature and morphology of the composite materials depicts their performance and characteristics that can be assessed. Some factors for example intrinsic properties, structural arrangement of the reinforcing particles in the matrix system and the relations between the constituents are of great significance. The intrinsic properties of reinforcements and matrix system decide the general order of properties that will play an important role in the composite. The interaction between the constituents of a composite sets the new characteristics which are very crucial for the automotive and aerospace applications. The shape and size of the individual particulate, their structural arrangement, distribution and the relative amount contribute to the on the whole performance of the composite. The important factors determining properties of composites materials are microstructure, size, volume fraction, homogeneity, and isotropy of the system and the technique used to manufacture the component. These are strongly predisposed by proportions and characteristics of the matrix and the reinforcements. The characteristics such as the modulus of elasticity, shear modulus, coefficient of thermal expansion, Poisson's ratio, and coefficient of friction are predicted in terms of the properties and concentration and the most commonly used.

2.1 Mechanical Properties

2.1.1 Hardness

The resistance to indentation or scratch is known as hardness. Brinell's, Rockwell's and Vicker's hardness testers commonly used to measure hardness. Song. W.Q. et al. [2] and Purohit et al. [11] studied that the reinforcing particles of Al_2O_3 and SiC are added to aluminium matrix to increase hardness and ultimate tensile strength**.** Particulate or platelets, generally ceramics which are oxides, carbides, nitrides and carbonates are used because of high strength, stiffness at room and at elevated temperatures. The common reinforcing elements are SiC, Al_2O_3, TiB2, B and Graphite. Dr. Fazlur et al. [16] reported that like the tensile strength and stiffness, the hardness also increases if heat treatment is used as a secondary operation.

Bharath V et al. [17] prepared 6061Al- Al_2O_3 metal matrix composite by stir-casting method and K. L. Meena et al. [18] aluminium (Al-6063)/SiC Silicon carbide reinforced particles metal-matrix composites. They reported that hardness increases with increase in wt% of Al-Al_2O_3/SiC particulates as shown in Figures. 1 & 2.

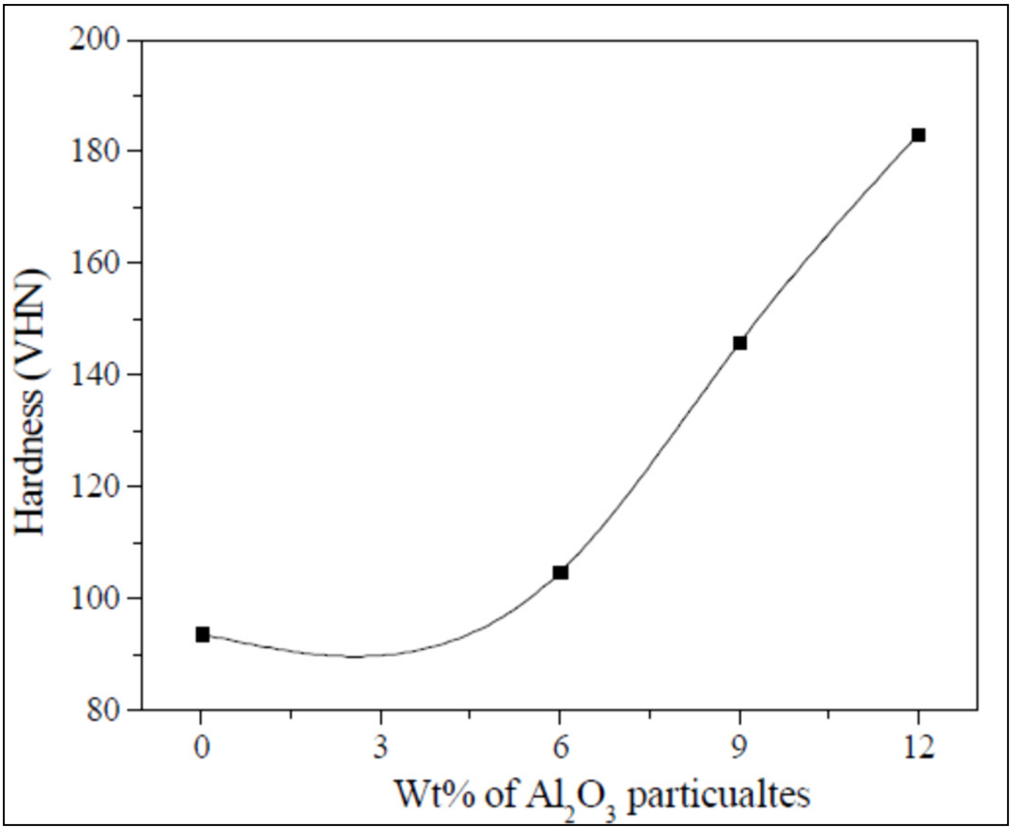


Fig.1. Variations in hardness of 6061Al before and after addition of different wt% of Al_2O_3 particulates

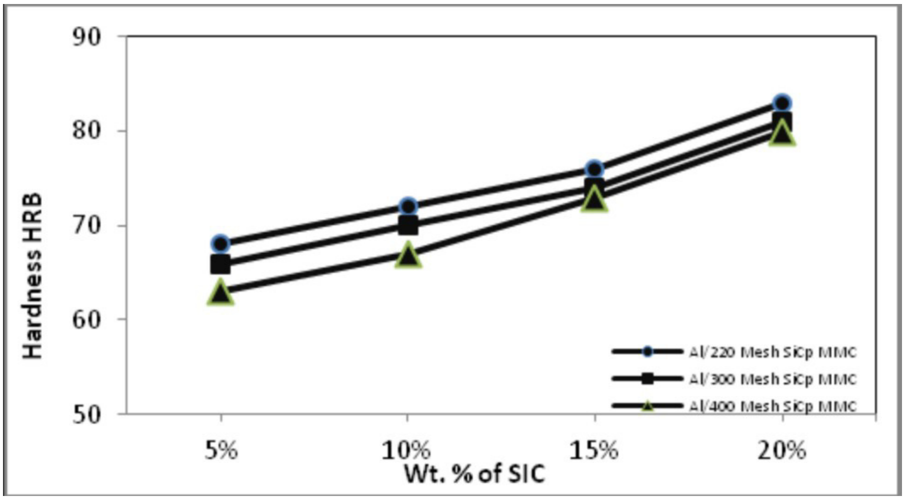
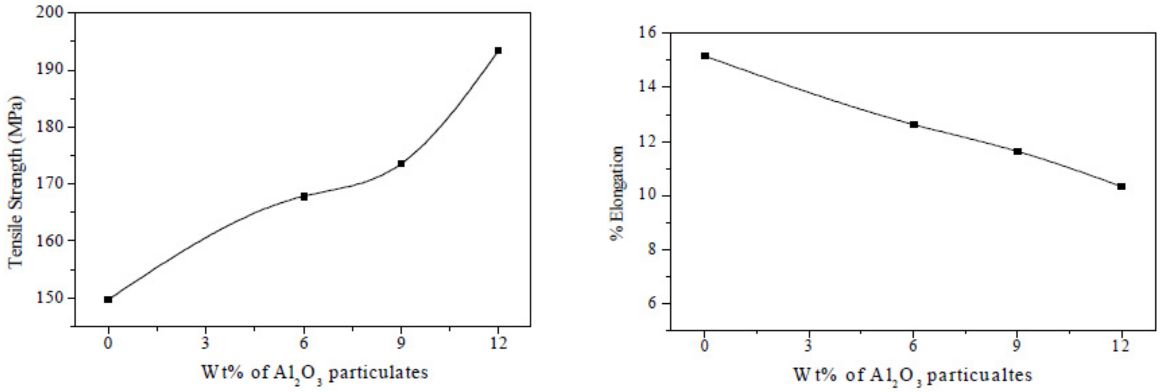


Fig.2. Hardness (HRB) Vs Weight% of SiC

2.1.2. Tensile Strength and Elongation

Bharath V et al. [17] and K. L. Meena et al. [18] shown the following results in Figures 3, 4 & 5.



(a) Variation in Ultimate Tensile Strength (b) Variation in % Elongation

Fig.3. Graphs showing the tensile test results of 6061Al-alloy before and after addition of Al_2O_3 particulates

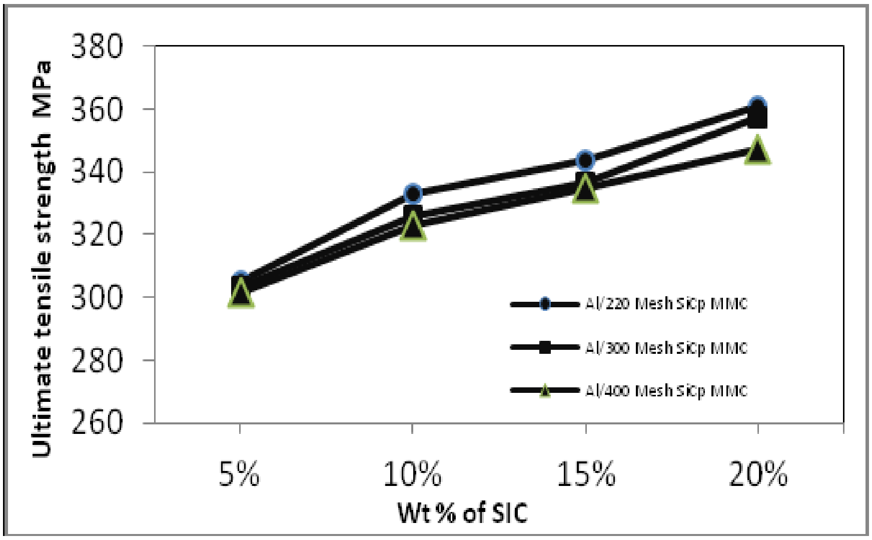


Fig.4. Ultimate Tensile Strength (MPa) Vs Weight% of SiC

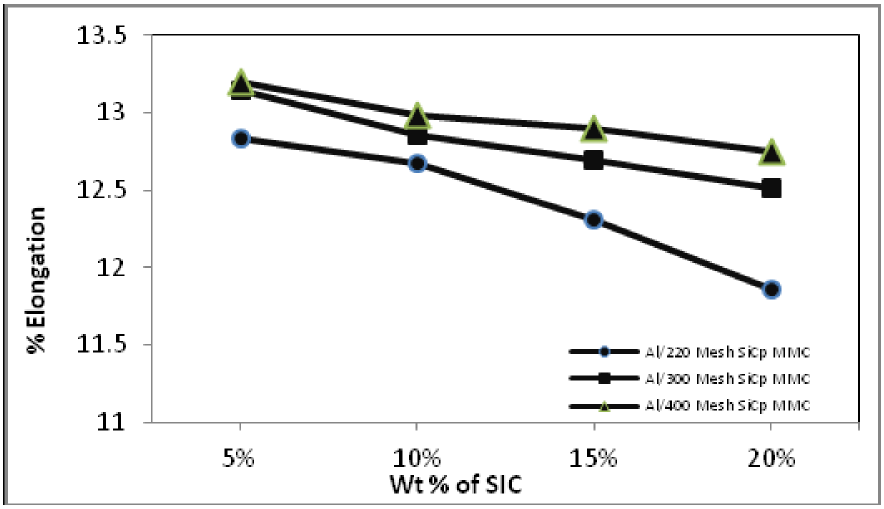


Fig.5. %Elongation Vs Weight% of SiC

2.1.3 Fatigue Resistance and Impact Strength

Frank V. Beaumont et al. [6] and Vencl A. et al. [10] reported that the fatigue resistance along with weight reductions is very important criteria for the metal matrix composites, particularly in the field of aerospace and automobile applications. N. Chawla et al. [5] studied the effect of SiC volume fraction and particle size on the fatigue resistance of a 2080 Al/SiC_p composite and reported that increase in SiC_p volume fraction and decrease in SiC particle size, results in increase of fatigue life in the composites.

K. L. Meena et al. [18] shown in their experiment that Impact Strength (Nm) decreases with the increase in reinforced particulate size (220 mesh, 300 mesh, 400 mesh) and increases with the increase in weight fraction(5%,10%,15%,20%) of SiC particles. Maximum Impact Strength = 37.01 N-m has been obtained at 20 % weight fraction of 400 mesh size of SiC particles as shown in Fig.6.

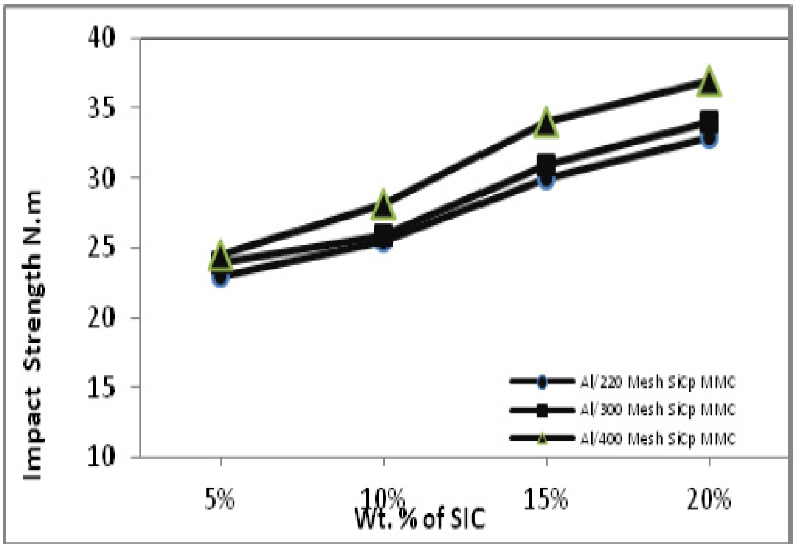


Fig.6. Impact Strength (Nm) Vs weight% of SiC

2.1.4 Wear Resistance

Purohit R. and Sagar R. [9] shown that a lot of wear resistant parts are used in cars, e.g. cam shafts, valves, shock absorber, piston rods and rings, bearings and others. Most of them are coated with a hard chromium layer which is a very popular layer with a high hardness of about 1100 HV and a good corrosion resistance.

Song W.Q. et al. [2] experimented the effect of thermal ageing on the abrasive behaviour of age-hardening 2014 Al/SiC and 6061 Al/SiC composites and resulted that raising the ageing temperature from 50°C to 250°C increased the hardness and abrasion resistance of the composite because of the precipitation of small inter-metallic compounds which are incoherent with the crystal structure of aluminium matrices.

2.1.5 Strength to weight ratio

Froes F. H. [1] recommended that improved performance in aerospace and automotive requires enhancement in the behaviour in the materials of construction. Weight reduction also translates to material property improvement and the greatest weight reduction is achieved by a density decrease, which gives a direct weight reduction. Therefore, the importance of the low-density structural alloys of aluminium, magnesium and titanium as shown in Figures 7 & 8.

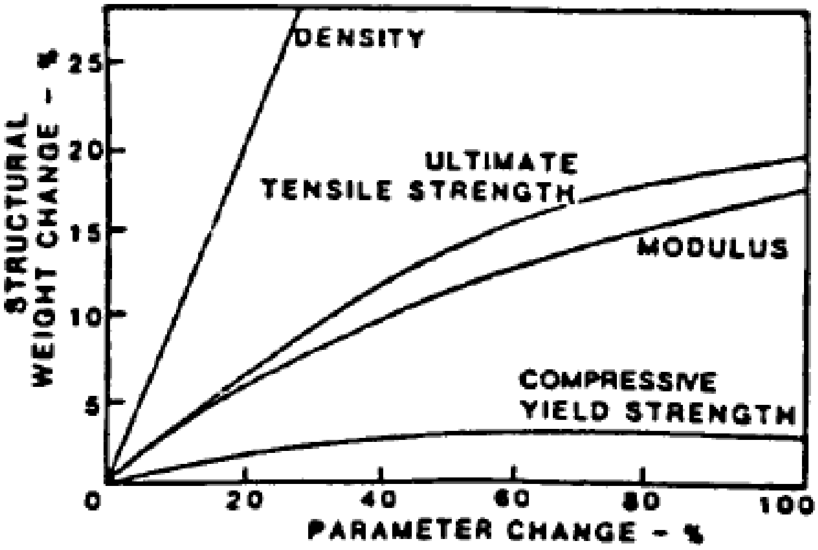


Fig.7. Effect of property improvement of structural weight

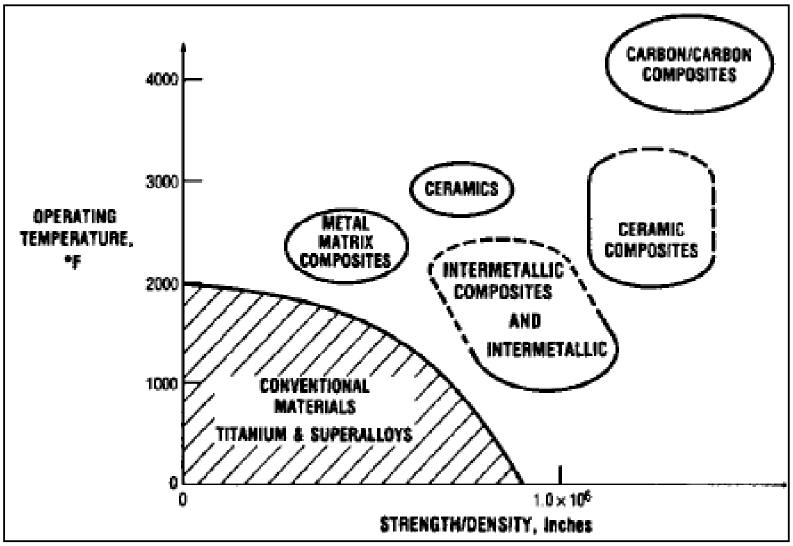


Fig.8. Temperature capability of various materials classes

2.1.6 High Temperature Properties

Dr. Fazlur al. [16] reported that Aluminium Metal Matrix composites for high temperatures applications like aerospace and automobile, a thermal barrier coating of PSZ, Super-Z alloy, Zirconia Toughened Alumina (ZTA) Alumina-Titania (Al_2O_3 + TiO_2) and Alumina could be plasma sprayed to impart maximum thermal resistance and thermal fatigue resistance to the components.

3. Trends in Aerospace/Automobile Applications

3.1 Aerospace

Song. W. Q. et al. [2] studied that the increased performance demanded of present day aerospace systems requires in turn an improvement in the materials of construction This applies to both airframes and engines. For example, fighter aircraft must operate over broader combat envelopes (Fig. 9) with supersonic persistence, at greater turn rates, high load factors and maximum Mach numbers. The major part that new and improved materials play in structural weight reduction is shown in Fig. 5. It can be seen clearly that the materials factor greatly exceeds the contribution made by other advanced technologies such as structural concepts, automated design and active load control, and flutter suppression.

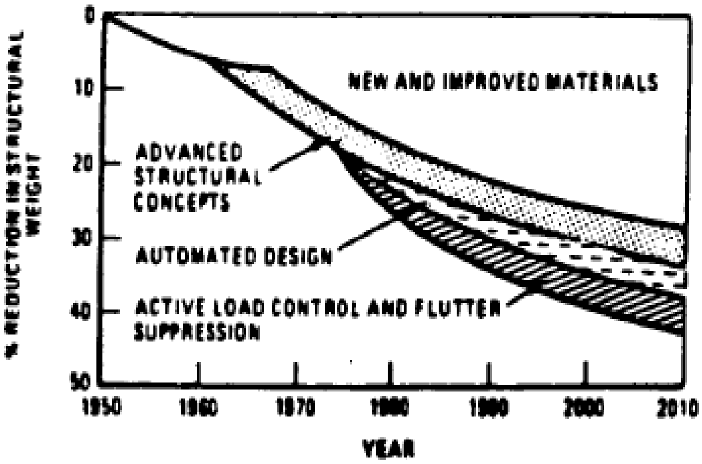
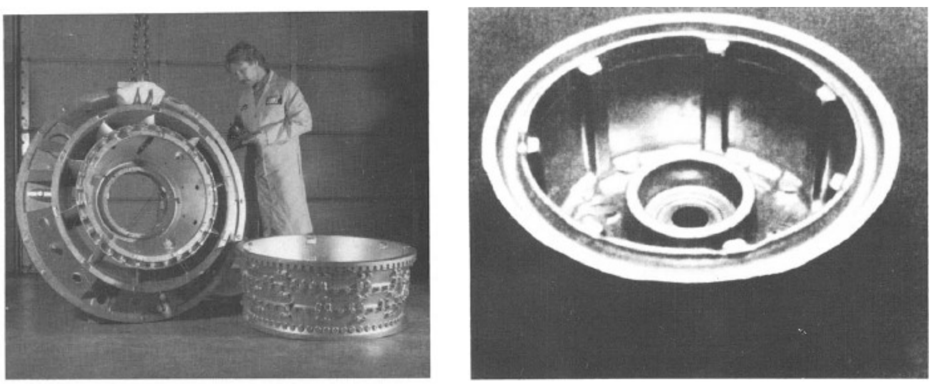
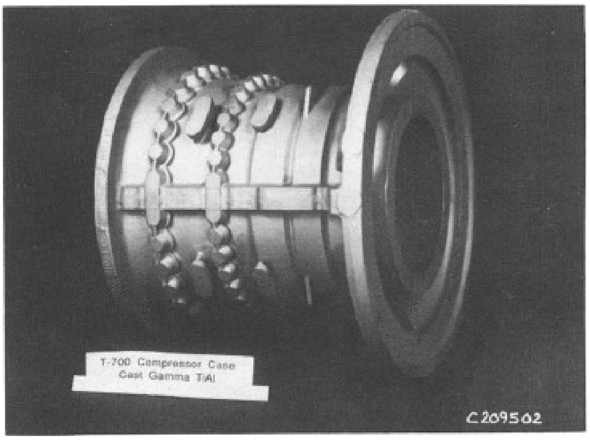


Fig. 9.Trends in structural weight reduction for fighter aircraft, showing the significance of new and improved materials

Because the aerospace industry can "afford" high cost, high-performance materials and processes, much more so than "Detroit", many new materials/processes have been evaluated for aerospace applications. Large conventional titanium engine parts have been produced by the casting approach (Fig.10), and the rapid solidification and mechanical alloying approaches have been used to fabricate a number of aerospace components such as the parts shown in Fig.



a) Large engine part casting b) Forged RS aluminium alloy Landing Gear wheel



c) GET Engine Compressor produced from cast TiAl
Fig. 10 Showing Parts of Aircraft

3.2 Automobile

Froes F.H. [1] shown that light weight materials can make a considerable contribution to enhanced fuel consumption, since a 10% reduction in vehicle weight translates to a 5.5% enhancement in fuel economy.
Anthony Macke et al. [15] studied that automakers are being subjected to increasingly strict fuel economy, while consumers are demanding better interior comforts and advanced electronic systems for safety, navigation and entertainment, all of which add otherwise unnecessary weight. Aluminium engine block, suspension components, body panels and frame members are increasingly common, in addition to the use of magnesium in components such as instrument panels, valve covers, transmission housings and steering column components. Aluminium-graphite pistons and liners were tested in gas and diesel engines and in racing cars, resulting in reduced friction coefficients and wear rates, Aluminium matrix nano alumina composite for connecting rods, and replacing components such as A/C pump brackets, timing belt/chain convers, alternator housing, transmission housing, valve covers and intake manifolds with aluminium fly-ash composites can reduce the vehicle cost and weight , thereby improve emissions and save energy. SiC reinforced aluminium brake rotors are incorporated in vehicles such as the Lotus Elise, Chrysler Prowler, General Motors EVI, Volkswagen Lupo 3L, and the Toyota RAVA-EV.

4. The Future of Light Metal Technologies for the New Millennium

Superior-performance aerospace and automobile systems can be developed using high-performance, lightweight composite or nanocomposite materials. Production of lightweight materials, based on aluminium, magnesium, titanium and titanium aluminides, with superior physical and mechanical characteristics, requires innovative synthesis techniques. A number of such synthesis methods have been recommended, including ingot/casting, rapid solidification, mechanical alloying, nano-structured materials, powder metallurgy, spray deposition, ultrasonic assisted stir casting, squeeze casting, thermo-chemical processing, metal-matrix composites and fusion joining. While enhanced performance is attractive, widespread use, particularly in automobiles, requires cost-efficient materials and processes.
The future development of light weight metals is very encouraged and is important to allow the energy effective and environment friendly production of automotive and aerospace components. Alloys and processing technologies today are not ideal and adequate enough to fulfil the demands of today’s industrial scenario and a lot of problems need to be solved through our consistent efforts of scientists and researchers. The amalgamation of alloying elements, forming and heat treatment processes are also not perfect but there are a lot of chances to create more effective and environment friendly processes to give added value to light metal mechanism that would be a right candidate for the applications in aerospace and automobile fields for coming future..

5. Summary

The present article highlights some of the new and exciting aluminium-based composite/processing and manufacturing technologies, which are promising for automotive and aerospace applications. The new materials, fabrication technology starting from metal powders has a huge potential to develop pioneering materials by more economical production systems, which will contribute to the development of highly efficient industrial technologies. The hardness of the composites including with UTS, impact strength, wear resistance, thermal properties were reviewed and on conclusion, it is discovered that as the reinforcement contents increased in the matrix material, the hardness of the composites also increased with increase in tensile strength and decrease in elongation. The P/M technology with sintering is very important to achieve better propertied in aluminium matrix composites for automobile and aerospace applications.

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