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SHEETS AND STRUCTURES MADE FROM PARTICULATE REINFORCED ALUMINIUM MATRIX COMPOSITES

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Abstract

The BRITE/EuRam project, which aims to develop the necessary technology base for the production of sheets and sheet structures made from particulate reinforced Metal Matrix Composites, commenced work in September 1991. Most activities have so far been concentrated on the production of forgings and extrusions. Little attention has been paid to the development of MMC sheets. Within this project, a European production route for MMC sheets and processes for secondary manufacturing (cutting, forming, joining, etc.) is now being developed because many stiffness-critical parts have a sheet-type geometry, especially in air- and spacecraft. The other objectives are evaluating material properties, numerical process modelling, and the production of stiffened sample structures.

The project has been divided into two parts. During the first part, production technologies such as spray deposition and powder metallurgy (Alusuisse-Lonza (CH), Raufoss (N)) and manufacturing technologies such as cold and hot forming, superplastic forming, shot peen forming, laser and abrasive water jet cutting, and joining by the diffusion bonding process (Aerospatiale (F), Deutsche Aerospace [D)) were studied. Process optimization will still be implemented within the second part of the project, but the main goal will be the synthesis of several manufacturing techniques resulting in the production of a demonstrator part using different selected manufacturing sequences for the same type of structure. The overall work on the project is extended and supported by basic investigations at the University of Aachen (D) and the Institute of Mechanics of Materials and Geostructures (G R), who implemented numerical modelling and optimization of forming processes at different temperatures and constitutive modelling for the special case of MMC. Mechanical testing will be carried out to characterize the parent material of own production as well as to investigate material properties after processing and manufacturing.

MMC sheets have been produced by spraying or powder mixing and hot pressing followed by an extrusion and hot plus cold rolling process. The target properties, defined as yield strength > 500 MPa, tensile strength > 600 MPa, elongation > 3% and Young's modulus > 100 GPa, were obtained using the Osprey technique as well as the PM route. After spraying N202/SiC/1 7p was stopped by Alusuisse-Lonza, the project is now concentrating on PM-2024/SiC/20p and PM-7021/SiC/20p. Tests which have been carried out on machining, corrosion, forming and joining behaviour showed that. nearly all conventional and also advanced manufacturing techniques can be applied to MMC material. However,' for some processes, especially hot and cold forming, rather high expenditure is needed compared to conventional alloys, and a decrease in mechanical properties may have to be taken into account. Consequently, further parameter optimization and improvement of the material quality is necessary. Two ways of producing a stiffened sample structure have been realized. A combination of hot forming and riveting as well as hot forming combined with diffusion bonding was applied,

Introduction

Due to a wide spectrum of realizable properties, metal matrix composites (MMCs) are highly appropriate to match the performance demands of upcoming decades. Combining different light alloys or high-temperature matrices with ceramic materials of various shape and composition, MMCS cover a broad field of applications in transportation, powerplants, machine and robot building, sports and other industries.

First industrial applications in series production currently became reality, however, primarily in Japan and the United States, which took the leading position in research on and development of MMCs. The continuation and intensification of research efforts in Europe will be necessary to strengthen the European position in the world market and to succeed against Japanese and American competitors. From the current point of view, MMC materials are considered as one key technology for future automotive and aerospace markets. It will be of major importance, however, to focus on the most promising materials and processing routes, taking into account economical aspects and the requirements of intended applications.

Technical Description

Development of the technology for European production of particle reinforced aluminium sheets:

Establishment of the production of sheets from particulate reinforced aluminium billets produced by spray deposition and powder metallurgy.

Selection. evaluation and optimization of appropriate further manufacturing processes for shaping. joining and assembly:

Sheet forming processes with special emphasis on shot peen forming and superplastic forming were selected, tested and optimized. The forming limits for cold and hot forming of the material and optimum forming conditions were established. Diffusion bonding processes such as transient liquid phase bonding and solid state bonding were tested and optimized. Machining and milling processes were selected and tested with special emphasis on laser and abrasive jet water cutting. Suitable process conditions were established.

Manufacture and evaluation of stiffened sample structures:

For demonstration and testing purposes a stiffened sample structure was produced by different manufacturing sequences.

Definition and development of appropriate material testing methods and evaluation of important material data:

Material testing methods were defined according to the special behaviour of particle reinforced materials and important material data on MMC sheets before and after processing were established.

Complementary studies concerning numerical modelling of the forming behaviour, reeveling, corrosion and repair:

Constitutive modelling of the material was enhanced. Recycling, repair and corrosion aspects were examined and discussed.

Results

Production of Material

Material production has been carried out using two different production routes. The Osprey technique was applied by Alusuisse-Lonza for producing N202 billets reinforced with 17'% SiC particles. The billets were then extruded to obtain a suitable size and geometry for rolling. Raufoss produced the 2024/SiC/20p and 7021/SiC/20p material by powder metallurgy. A special process developed for superplastic MMC [1] was applied to 'produce sheet material. This process includes several production steps, such as powder mixing, cold compaction, inert degassing, hot compaction and also extrusion. After having obtained the extrusions, hot rolling was performed in many steps of low reduction and with several intermediate softening heat treatments to obtain sheets. Cold rolling was applied for surface finish and to obtain very small grain sizes for superplastic behaviour. As a reference, 2124/SiC/1 7p, 8090/SiC/17p and 7475/SiC/1 7p were bought from BP.

A rather homogeneous particle distribution was found in the Osprey material (average particle size 8 pm) (Fig. 1) as well as in the PM material (particle size 3-5 μm) (Fig. 2). Visualization of grain boundaries was very difficult and only possible after recrystallization heat treatment and well-defined etching. The grain sizes determined are 7 to 20 pm, depending on the rolling process and the heat treatment condition. The BP material has a similar microstructure, However, additional small parts of particles have been observed within the matrix,

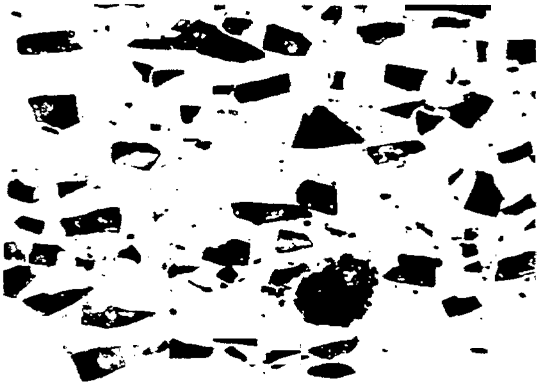

Fig. 1: N202/SiC/1 7p 700:1

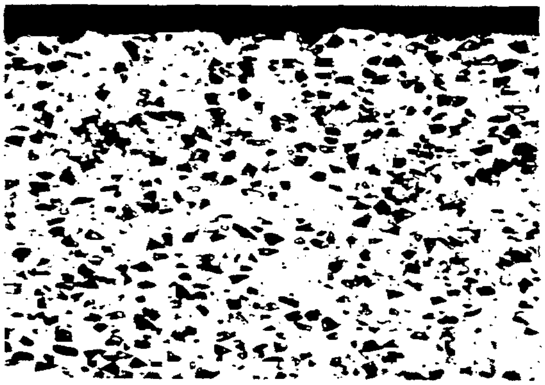

Fig. 2: PM-2024/SiC/20p 700:1

Material Properties

The target properties, defined as yield strength > 500 MPa, tensile strength > 600 MPa, elongation > 3% and Young's modulus > 100 GPa, were obtained using the Osprey technique as well as the PM route.

The mechanical properties of all MMC materials tested in T4 condition are listed in table 1a. The influence of different heat treatment conditions on mechanical properties is shown in table 1b.

Material	Rp0.2 [MPa]	Rm [MPa]	A [%]	Z [%]	E [GPa]
AA2024	**328**	**493**	**23**	**28**	**72**
2124/SiC/20p	**446**	605	**4**	**6**	97
2024/SiC/19p	393	62(3	6	7	103
N202/SiC/1 7p	388	573	7	7	103
7475/SiC/1 9p	466	591	3	-	98

Table 1a: Mechanical properties in **T4** condition, longitudinal direction

Material	Heat treatment	Rp0.2 [MPa]	Rm [MPa]	A [%]	Z [%]	E [GPa]
N202/SiC/17p	**T3**	**495**	**580**	**6**	**9**	**99**
	T4	**388**	**573**	**7**	**7**	103
	T6	538	617	3	6	102
7021/SiC/1 9p	T4	399	541	4	9	102
	T6	485	575	4	7	103
	T?	411	493	5	13	103

Table 1 b: Mechanical properties ofN202RiC/17p and 7021/SiC/20p in several heat treatment conditions, longitudinal direction

A special testing equipment for shear load application was designed and built by IMMG. This shear device can load **a** specimen with 100% true shear stresses (Fig. 3) due to a controlling system which controls each of the 4 independent hydraulic cylinders. To realize the specimen shown (Fig. 3) from sheet material, a 5 mm thick sheet was adhesion bonded with steel plates to obtain the calculated specimen geometry and consequently true shear stresses (Fig, 4).

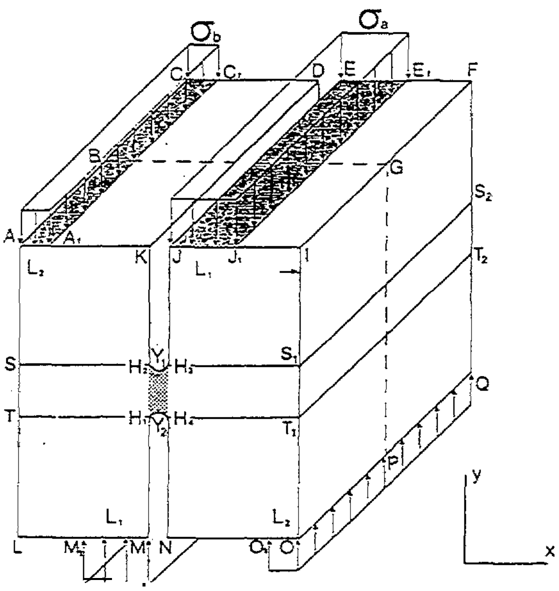

Fig. 3: Specimen especially designed for shear device

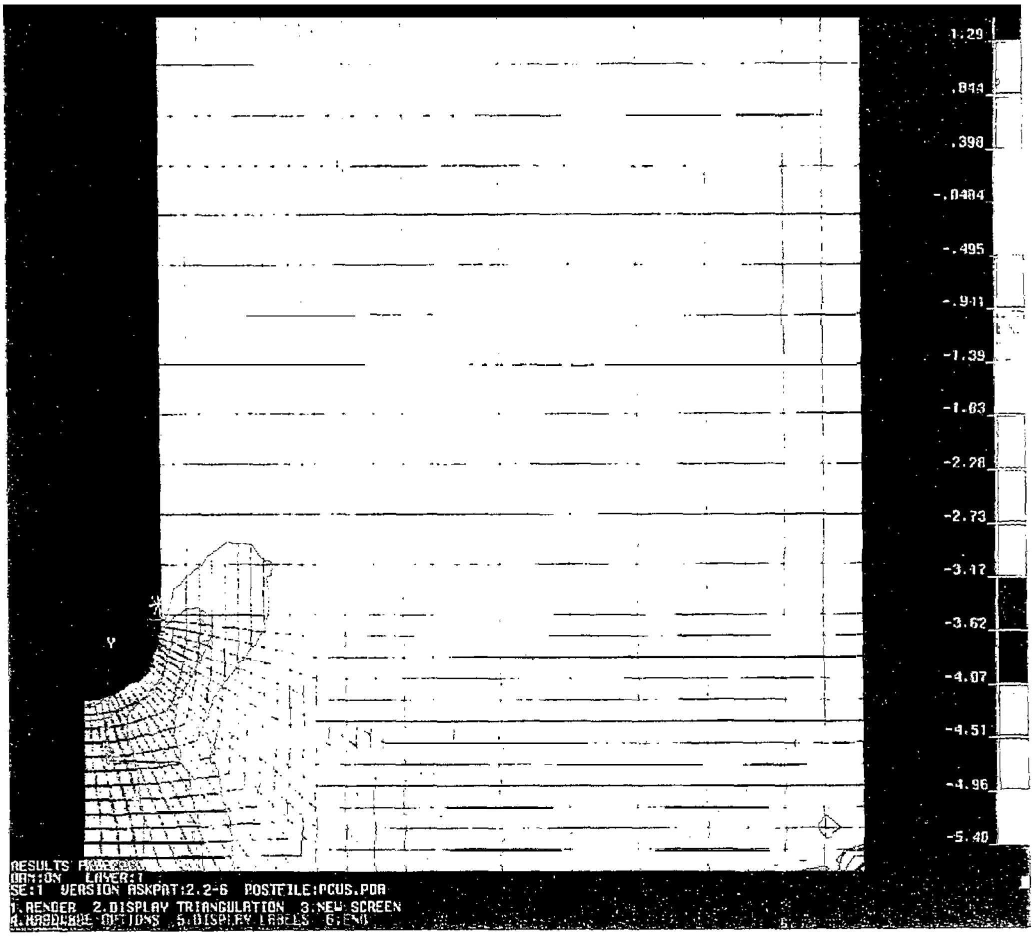

Fig. 4: FEM **calculation** of **shear stresses**

Cutting Techniques

Very high wear during machining with standard tools can be observed. Therefore several new cutting techniques have been tested for MMC application. Methods such as diamond milling, laser cutting and abrasive water jet cutting are more efficient than conventional machining techniques. However, a problem inherent in the fast techniques laser cutting and abrasive cutting is the surface roughness of the cut edges. A fatigue test showed that the very smooth surface after diamond milling reaches a 20% higher fatigue limit than after laser and abrasive water cutting. The consequence drawn from this investigation is the recommendation to use laser and abrasive cutting for rough machining only and to do the finish with diamond tools.

Forming Techniques

Various forming techniques such as superplastic forming, hot forming and shot peen forming have been tried with the MMC sheet material, The hot forming technique carried out in a die under homogenization temperature (Fig. 5) turned out to work very well. As is commonly known, superplastic forming is a very grain-size-sensitive process.

Due to this, the success of superplastic forming depends considerably on highly reproducible and well adjusted production, material rolling and forming parameters [2]. Laps and other flaws initiated cracks during forming (Fig. 6). To date it has only been possible to do superplastic forming with MMC material from BP (Fig. 7) and the PM-2024/SiC/20p alloy produced within the project by RF. With shot peening, large radii only could be realized, which are not suitable for stiffener production. A new technique, which is a combination of shot peening and bending, will be applied for obtaining smaller radii of about 6 mm.

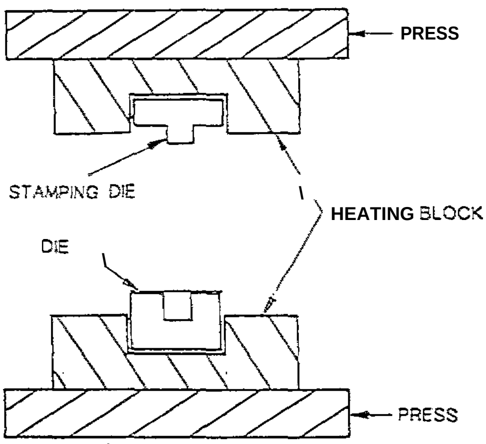

Fig. 5: Hot forming process

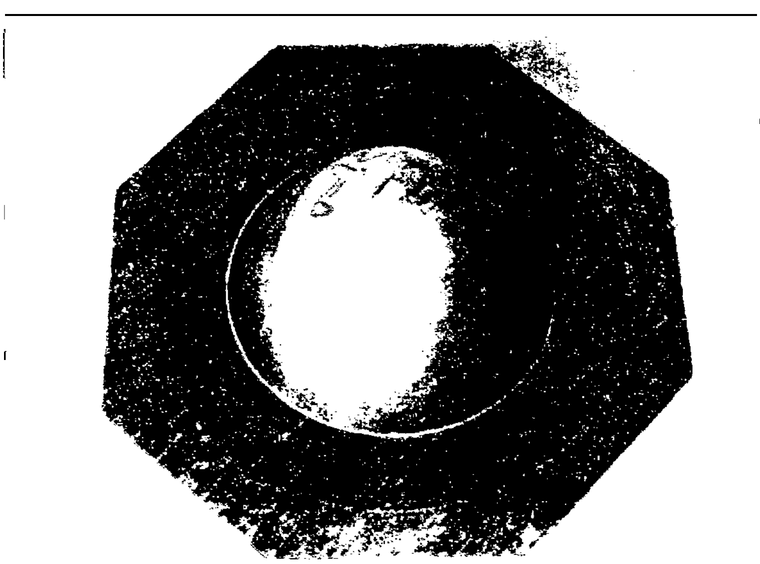

Fig. 6: Superplastic forming process stopped after cracking

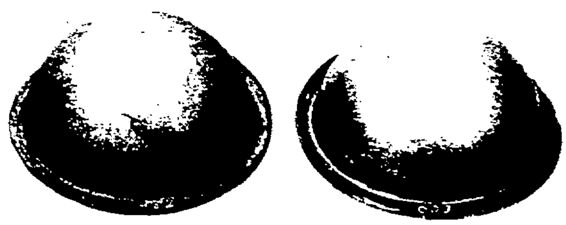

Fig. 7: Superplastic formed hemispheres without any defects

Bonding Techniques

Several combinations of materials and brazing foils to realize transient liquid-phase bonding have been investigated. In general, the diffusion bonding process works similarly to conventional aluminium materials, and only the parameters were varied (Fig. 8). The alternative, liquid-phase bonding, could be applied easily to MMC material (Fig. 9), but depends on the content and combinations of the brazing foils.

Fig. 8: Diffusion-bonded 21 24/SiC/1 7p

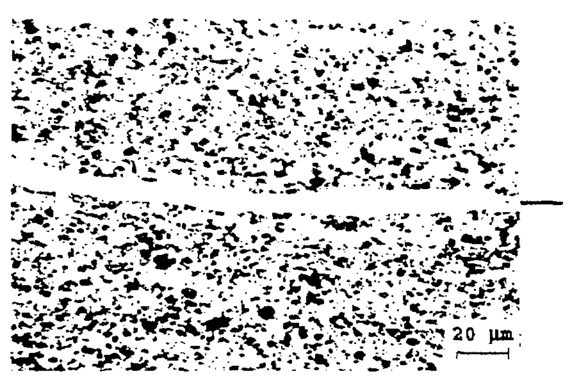

Fig. 9: Transient liquid-phase-bonded material 7475/SiC/17p material with AlGeSi brazing foil

Production of Sample Structures

A stiffened panel has been chosen to realize a realistic structure which can also be tested easily. Two ways of producing a stiffened sample structure have been identified, namely a combination of hot forming and riveting as well as hot forming combined with diffusion bonding. Both kinds of structures have been realized (Fig. 10 and 11).

The hot-formed and riveted structure has' been mechanically tested but the results showed some decrease in properties due to defects (flaws} caused by the hot forming process. The hot formed and diffusion bonded structure was inspected metallographically.

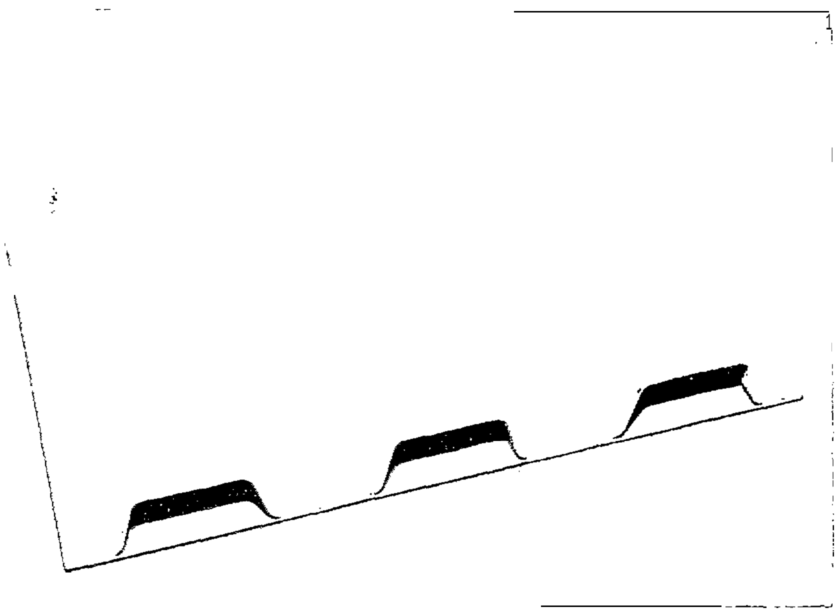

Fig. 1 U: Stiffened structure produced by hot forming and riveting

Conclusions

The project was successful in its investigations and is characterized by the excellent co-operation of all the partners involved. MMC sheet material with N202, 2024 and 7021 matrix alloys reinforced with SiC particles were produced using a suitable production process. A suitable process of this type contained steps such as extrusion, hot rolling by many **small** reductions, and final cold rolling with low reductions. The material obtained had quite a homogeneous particle distribution with a particle size of 3 to 10 µm. The mechanical properties showed a gain of 15% in strength and 35% in Young's modulus. In contrast, the ductility decreased 'by about 80% to an acceptable mean elongation of 5 to 6%. Nearly all manufacturing techniques used for conventional aluminium alloys, such as diamond cutting, hot forming, diffusion bonding and liquid-phase bonding could also be applied to aluminium MMC's with some increased expenditure. Finally, the production of a stiffened demonstrator part was realized by two different sequences; hot forming with riveting and hot forming with diffusion bonding. However, the mechanical properties have been negatively influenced by microcracking induced by the hot forming steps during manufacturing. The problems still remaining involve mainly the relatively high price and inadequate quality of MMC, especially MMC sheet material. Formability problems could be avoided by involving other near-net-shape manufacturing techniques, e.g. extrusion of profiles.

The application range of particulate reinforced aluminium is not restricted to aerospace products. Other fields like the automotive. train, robot, electronics and sports equipment industries may take advantage of the technical benefits of these materials as well. Interest is growing, particularly in areas of small-scale series production. The main advantage utilized may not only be the improved stiffness but wear resistance or the thermal expansion coefficient.

Acknowledgements

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