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A Review on the Processes involved in the Manufacturing and Fabrication of HMMCs and Subsequent Change in its Properties

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Abstract:- Metal matrix composites have revolutionized the material industry by producing lightweight materials with high mechanical properties such as hardness, impact, compressive strength with corrosion resistance. Their invention has contributed effectively to the aerospace industry and automobile industry. This paper reviews different works on the effects of various fabrication and manufacturing processes on the nature of MMC's, the change in properties that makes it suitable for industrial purpose and also its various applications. The focus is also embedded upon the microstructural changes that occurs once the Metal Matrix Composites are exposed to heat treatment. Unlike the conventional techniques, the paper also focuses on the fabrication methods that produce high quality material in high amount

Keywords:- *Hybrid Metal Matrix Composites; Powder Metallurgy; Stir Casting; Metal Matrix Composites;*

I. INTRODUCTION

A metal matrix composite (MMC) contains at least two constituents, one being a metal necessarily and the other material being a different metal or another material, such as a ceramic or organic compound. When there are at least three constituents present, it is called a hybrid composite[1]. The parent metal containing the greatest composition is stacked by other layers of metal, layer by layer or mixed evenly in uniform proposition. This is then heated below its melting point for a particular amount of time. Hybrid composites are found to be light weight with increased amount of hardness and other mechanical properties. A technique in which more than one reinforcements are incorporated together in order to get better mechanical properties such as stiffness, high strength to weight ratio, hardness etc. is called Hybridization. Composites made by hybridization usually consist of two or more reinforcements in addition to its parent matrix. These composites are manufactured by strengthening the matrix phase with two or more materials of variable properties[2]. Composites are non-homogeneous mixture of two or more homogeneous materials at a macro-scale, which are fused collectively. By this technique, desirable properties are achieved in a composite. Many natural materials such as bones and woods, for instance, are considered as composite[3]. Human made composites such as laminated woods and straw are used since thousands of years. Hybrid Composites have the capability to replace composites with single reinforcement due to their better properties[4].

A. Matrix

Aluminium, Magnesium and Copper are the most considered matrix metals owing to its high specific strength. Aluminium and Magnesium are most widely used due to low density and machinability. Elements like Silicon, Zinc, Magnesium, and Copper are soluble to the required amount which makes them feasible to be used as key alloying elements[5]. Particle size have a significant role in the MMCs[4]. The thermal expansion of matrix can be reduced by grain refinement thereby increasing the strength of the matrix. It also enhances with decrease in grain size but overall output is not improved significantly. The geometry and volume of the reinforcements determine the toughness of the composite[6].

B. Hybrid MMCs

Hybrid MMCs is manufactured by reinforcement of the base metal with reinforcements that have different properties. These matrix composites are a combination of more than one reinforcement particle and are capable of enhancing the mechanical properties of the matrix composite. The performance of hybrid composites is a cooperative effect of the individual constituents in which there is a better balance between the inbuilt advantages and disadvantages. Silicon carbide, Alumina, Boron Carbide, Tungsten Carbide, Graphite, single or multi Carbon Nanotubes and Silica are few of the reinforcements which are used, but silicon carbide and Aluminium oxide are preferred over other reinforcing materials [2].

C. Fabrication Technique

Different techniques are used for the fabrication of HMMC's like Mechanical Alloying, Infiltration, Stir Casting, Powder Metallurgy, Squeeze Casting and Ball Milling. Stir Casting and Powder Metallurgy are the broadly used techniques.

➢ *Stir Casting Method*

The process involves melting the parent ingot in the furnace at a specific temperature. The impurities are removed and the melt is stirred using a mechanical stirrer at a specific rpm. During the stirring process pre-heated reinforcement particles are added. After sometime, the molten metal is poured into the preheated die cavity within a few seconds through a pre-heated pathway from pouring furnace. The casted samples are then separated from the cavity [1].

Advantages	***Disadvantages***
1.Low cost 2.Simple instrumentation 3.High production rate 4.High density than PM composites 5.Less porous 6.Better hardness than PM 7.Continuous Matrix Media	1.Non uniform distribution of Nano particles 2.Weaker boding of matrix and Nano particles 3.Large free zone 4.Complex process control

Table 1:- Advantages and Disadvantages of Stir Casting [1]

➢ *Powder Metallurgy Method*

In this process the metal powder is mixed with the reinforcement with definite percentage**.** The mixed powder is placed in a die and compressed using uniaxial pressure**.** These compacts are then sintered at a specified temperature for a specific time period and then cooled in air or other medium to obtain the MMCs.

Advantages	***Disadvantages***
1.Better distribution of Nano particles 2.Easier control of Matrix structure 3.Better bonding of Matrix and Nano particles	1.High complexity 2.Expensive 3.High portions of porosity 4.Less density 5.Less hardness than stir casting method. 6.Discontinuous Matrix media

Table 2:- Advantages and Disadvantages of Powder Metallurgy [1]

II. LITERATURE SURVEY

N. G Siddesh Kumar et.al (2020) studied that specific wear rate of Al2219, Al2219/2%-B_4C composite increases at elevated temperature. The wear rate gradually increases due to the rise in temperature from 500°C to 1000°C at a rate of 250°C. However, there is significant decrease in the specific wear rate of Al2219/2%B_4C/2%MoS_2 hybrid composite at higher temperature. This happens due to the formation of surface oxide layer at higher temperature and also due to the presence of MoS_2 particles, resisting the wear and improvement in thermal stability of Al2219/2%n-B_4C/2%MoS_2 hybrid composite[8].

K. Sunil Kumar Reddy et.al (2020) studied the thermo-mechanical behavior of Aluminium-based HMMCs that contain wavering percentage of Graphite (3 wt%, 6 wt%, and 9 wt%) along with 10 wt% of Silicon Carbide (SiC). Results specified that the tensile strength of HMMCs and its hardness increase with increase in graphite content, with 10 wt% of SiC. The results also indicated that the reinforced Aluminium MMCs has better properties when equated to parent Aluminium alloys (unreinforced). The Coefficient of Thermal Expansion (CTE) and Thermal Conductivity (TC) of HMMCs with fluctuating temperature ranging from 50^0C to 300^0C decreased with increase of graphite reinforcement with 10 wt% SiC[9].

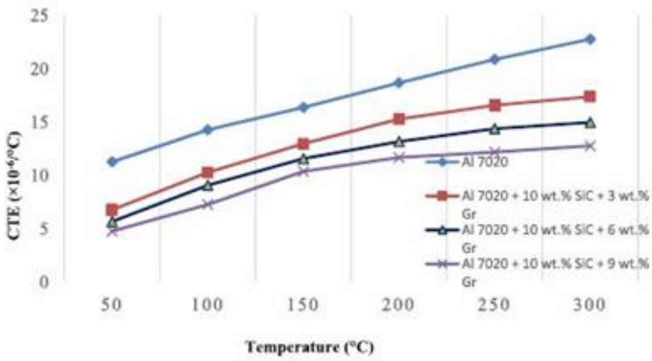

Fig 1:- CTE v/s Temperature graph [9]

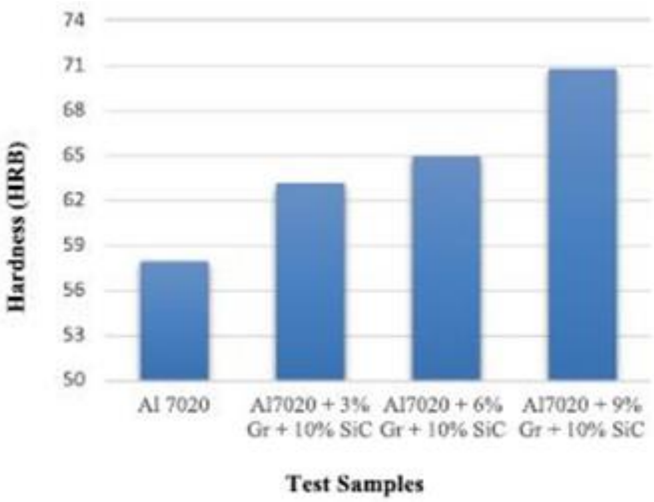

Fig 2:- Graphical representation of Hardness of Test Samples [9]

V.Boobesh Nathana et.al (2019) studied the mechanical, metallurgical and thermal properties of Aluminium HMMCs, its uses and also compared the properties with non-reinforced Aluminium alloys. Aluminium 7075 alloy with wavering mass percentage of 2%, 4%, 6% and 3% ZrO_2 was selected for the study and Stir casting method was employed for fabrication. Various mechanical tests such as tensile, hardness, and compression test were done to compare the properties and it was revealed that the scratch resistance, impact energy, compressive and tensile strength was increased with increasing 6% Silicon Carbide and 3% ZrO_2. Also after metallurgical analysis, homogeneous scattering of reinforcements was observed which is one of the characteristic of MMCs made from stir casting technique[6].

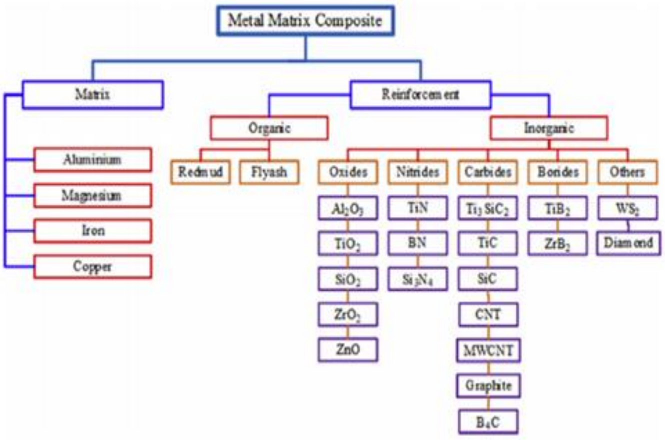

Fig 3:- Several reinforcement and matrix materials used for development of MMCs [4]

Fig 4:- Stir Casting Equipment [6]

Ashish Kumar et.al (2020) focus on the comparative study of the mechanical properties of MMCs through Stir casting technique and Powder Metallurgy method. The material selected for the study was A356 Aluminium alloy reinforced with MgO nanoparticles. This paper also briefs about the reason for which MMCs have an important role in the industry today. The method of fabrication using powder metallurgy and stir casting is explained step by step along with the different processing temperatures. Results indicated that samples made by powder metallurgy displayed more porosity when compared to stir casted specimens which resulted in higher density of casting samples. Hardness and compressive strength measurements denoted that the addition of MgO nanoparticles to the A356 alloy matrix improved the mechanical properties when compared to pure A356 alloy. From the results, it was clear that stir casted composites have dominant properties while powder metallurgy composites were simple and cost effective[4].

Hossein Abdizadeh et.al (2013) focus on the substantial aspects of MMCs such as implications of various reinforcements, various problems faced by it and future applications of composite. It also discusses about the functional and structural applications of MMCs. This paper also gives the reader about what a metal matrix composite is and how it is fabricated. Also it discusses about the various forms of reinforcements used such as fiber, flake, laminar, particulate and interpenetrating type. It also tells that Aluminium is the most commonly used matrix because of its availability and processability and also its cheaper. Further, it discusses about furnace design for the production of MMCs and is represented as a flow chart listed below[10].

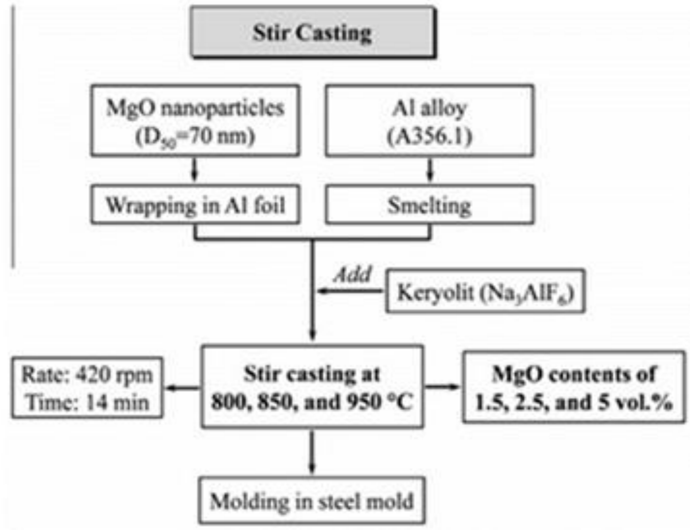

Fig 5:- Flowchart representing the Stir casting method for fabrication of Al-MgO Nano composite [10]

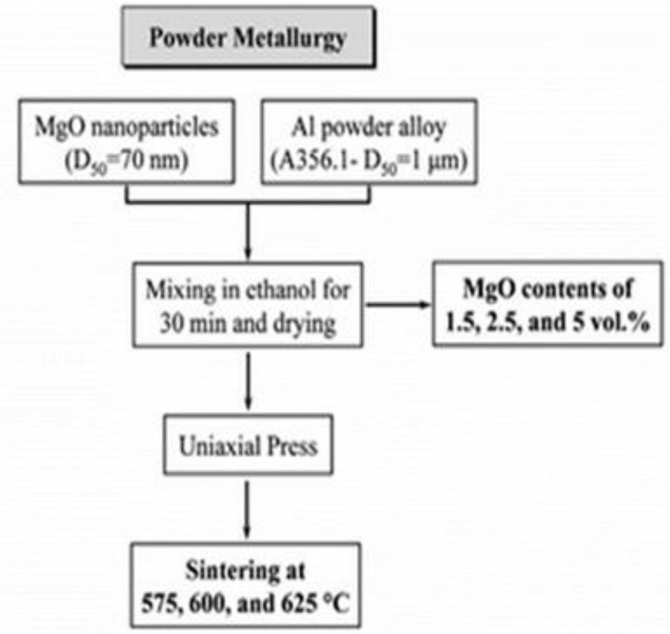

Fig 6:- Flowchart representing the Powder Metallurgy method for fabrication of Al-MgO Nano composite [10]

Towards the end, it discusses on the effect of squeeze pressure, reinforcement size, stirring speed, stirring time, melting temperature and design of the stirring blade on the properties of MMCs produced through stir casting technique[10].

AKM Asif Iqbal and Yoshio Arai (2015) studied about the low-cycle fatigue (LCF) behavior, mainly the fracture opening mechanism in a cast HMMC and analyzed their properties experimentally and numerically. The three-point bending test were conducted on the specimen followed by fractographic examination which was carried out to analyze the fracture opening site. Experiments displayed that micro cracks in the LCF started from the particle–matrix interface which was positioned in the hybrid clustering region. Due to continued fatigue cycling, interface debonding occurred, creating secondary micro cracks which thereby coalesced with other nearby micro cracks. Finite element method was used to develop the three dimensional unit cell model of HMMCs that contained the clustering and non-clustering regions of reinforcement. The stress–strain areas in both the reinforcement clustering and non-clustering regions were identified and analyzed. The numbers established that the stress concentration occurred on the reinforcement–matrix interface was situated in the clustering region [2].

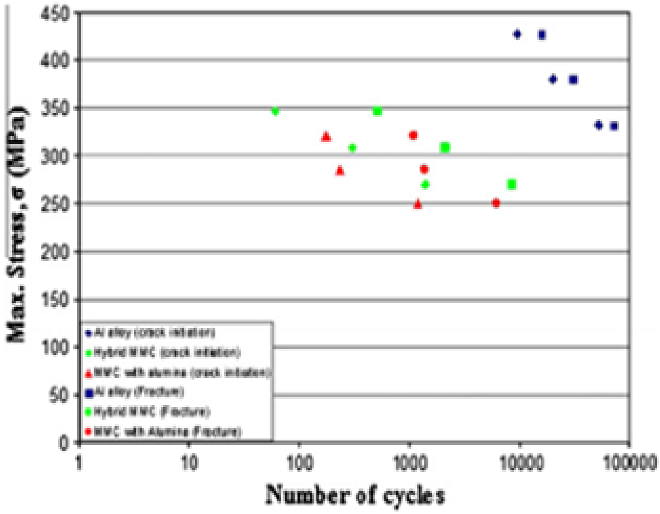

Fig 7:- No of cycles for crack opening & final failure at different stress level [2]

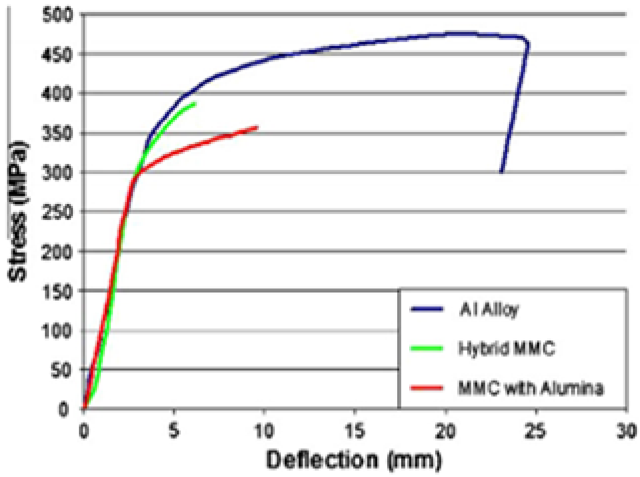

Fig 8:- Nominal bending stress versus deflection curves under monotonic loading [2]

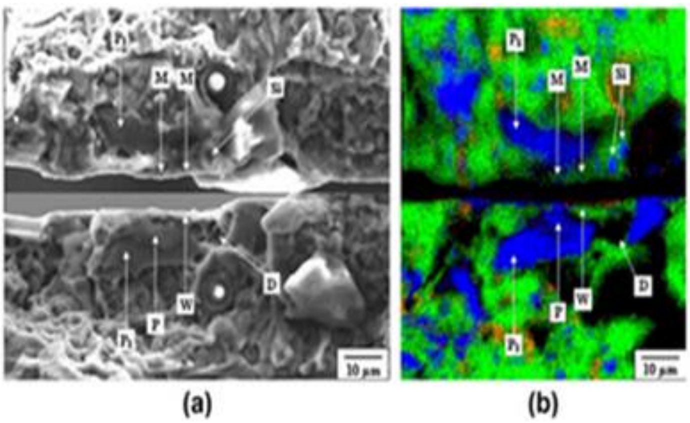

Fig 9:- Fracture surface containing micro crack initiation site in a group of SiC particle (a) SEM image (b) EDS mapping analysis [2]

A. Abbreviations and Acronyms

Fig. 9 shows the SEM micrograph of the fracture surface containing the micro crack initiation site in a group of SiC particles. In Fig. 9a, the flat dark area resembles to the location shown by the Particle arrow. Figure 9b shows the EDS mapping[2].

N. Rajesh Jesudoss Hynes et.al (2017) carried out a research on Friction Welding of AISI 1030 steel and hybrid AA6063-6SiC-3Gr matrix composite, that was found hard to weld by conventional fusion welding technique. Silicon carbide and graphite particle reinforced AA6063 hybrid composite were developed successfully using stir casting method and the joining feasibility of AISI1030 steel with AA6063-6SiC-3Gr hybrid composite was studied by friction stir welding process.

In the course of friction stage welding process, the reinforcement used were particulates of SiC & Graphite, in order to improve the resistance to flow which thereby leads to better mixing of parent material and reinforcements resulting in lesser strength of the dissimilar joints. In order to remove this trouble, Aluminium alloy 1100 inter layer was used while welding the composite to AISI1030 steel. Trials were conducted using Taguchi based design of experiments (DOE) technique. Also to analyze the relation between the parameters of the friction stir welding process, multiple regressions methods were employed.

Microstructural inspection revealed three different zones which are fully-plasticized, partially-deformed and unaffected-base material zones. Fully plasticized zone mainly consists of ultra-fine dynamically recrystallized grains of about 341nm size. Existence of intermetallic Fe_2Al_5 at the interface was confirmed by EDX Analysis. From the analysis using DOE, it was clear that speed of rotation and the thickness of interlayer donate about 39.0% and 36.0% correspondingly in calculating the impact resistance of the joints. It was established that joining with 1.5mm intermetallic layer provided better and efficient joints. Also the regression model that has been developed can be utilized to forecast the shortening axial distance and impact resistance of the joint with adequate accuracy[11].

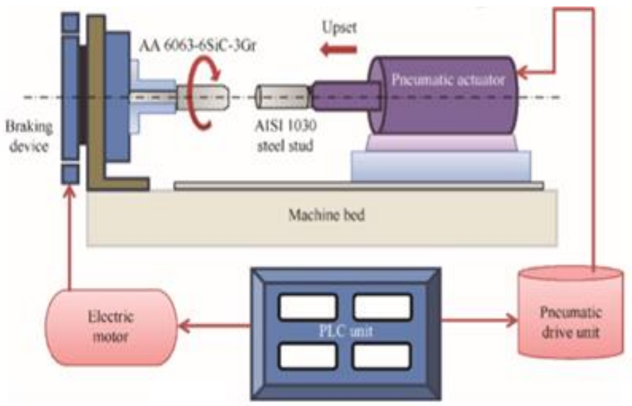

Fig 10:- Friction Stir Welding Equipment [11]

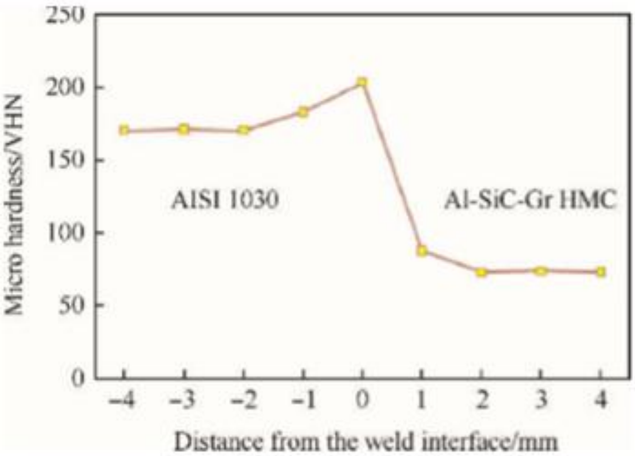

Fig 11:- Graph between distance from weld surface and micro hardness [11]

Fig 12:- Friction welded AISI 1030/AA6063-6SiC-3Gr joint [11]

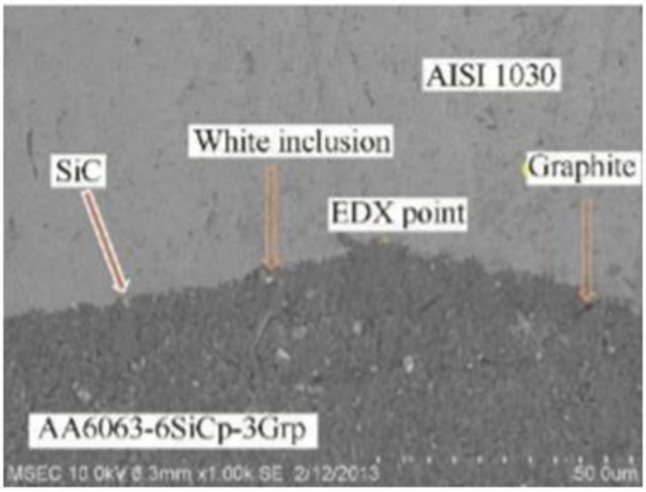

Fig 13:- SEM Micrograph at the interface of AISI 1030/AA6063-6SiC-3Gr joint [11]

Omalayo Ikumapayi et.al (2019) mainly focused on the friction stir processing of Aluminium Hybrid metal matrix composites Friction Stir processing is a method derived from friction stir welding in which there is a micro channel or small groove holes that contain the reinforcement phase which sometimes be made on matrix material. This technique of the Aluminium alloys has been known across various industries due to its capability to fabricate good AHMMCs in solid phase. It is easy, promising and economical to make AHMMCs using FSP technique. Benefits of Friction Stir Processing are refinement of grains, homogeneous processed zone, homogenization and densification of precipitates. These features make Friction stir processing more advantageous than other conventional metal working techniques. This paper also describes about the various challenges confronted by Friction Stir processing such as sticking of the substrate to the backing plate when processed substrate is of smaller thickness, how to improve fatigue property, tool wear and joining strength etc. On the conclusion, it also briefs that Aluminium Metal Matrix Composites have an unbeatable set of composite properties such as good corrosion resistance, high wear and oxidation resistance, high strength to weight ratio, high thermal and electrical conductivity, superior damping abilities, high fatigue strength and creep resistance [12].

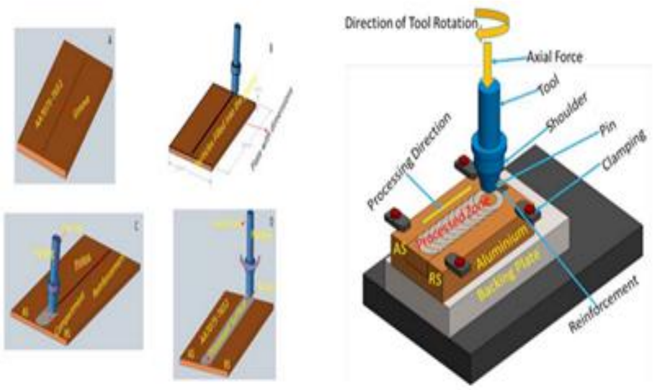

Fig 14:- Schematic of a typical FSP [12]

Kanhu Charan Nayak et.al (2020) mainly focuses on the investigation of properties of sintered cylindrical HMMC samples. Four varieties of HMMCs were prepared from Al powder combined with 3 and 8 % of alumina and, 2 and 7 % of SiC. Five different combinations of temperatures and sintering time were employed. This paper also conveys that powder metallurgy route is a highly cost effective and complex parts can be made close to dimensions. Due to this reason, this technique is used in aerospace, automotive and electrical industries. The mass volume ratio and scratch resistance of each specimen was calculated and cold compression test was also conducted for estimation of compressive strength[13].

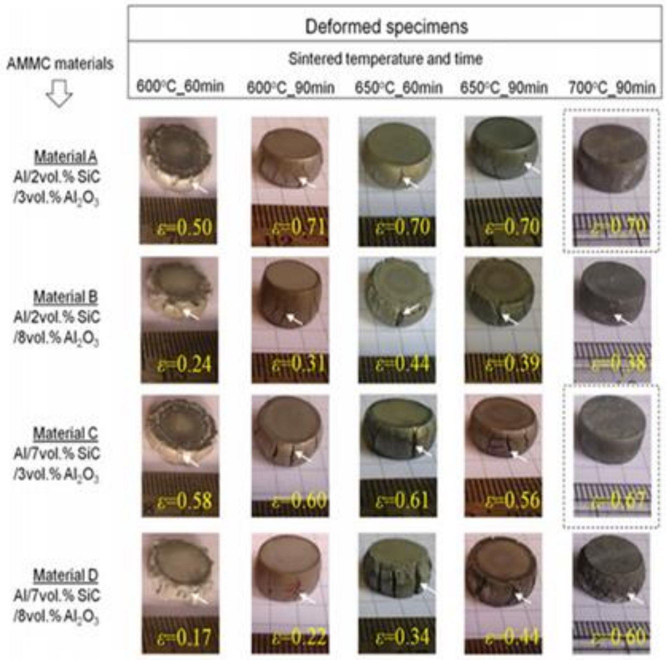

Fig 15:- Al-SiC-Alumina composites that are deformed after different sintering conditions [13]

Shakil Hossain et.al (2019) studied the Aluminium-based hybrid metal matrix composite that were developed by Stir casting method. Al_2O_3 content is fixed as 1 wt% and SiC content varying from 0 wt%, 2 wt%, 4 wt%, 6 wt%, and 8 wt% as reinforcements. Micro structure, mechanical properties such as wear behavior of prepared samples have been examined. The results indicated improvement in hardness and wear behavior due to addition of Al_2O_3 and SiC reinforcements into the Aluminium Al-6103 grade matrix. Also 8 wt% SiC and 1 wt% of Al_2O_3 reinforced AMCs gives maximum hardness value. Optical micro-graphs shows the unvaried dispersion of SiC and Al_2O_3 particles in the Aluminium matrix[14].

III. FUTURE SCOPE

The future prospects of Hybrid Metal Matrix Composites include the integration of HMMCs of very low percentage of volume which will help in weight reduction and achieve unique properties. Another important benefit of this composite is in the field of aerospace where HMMC's can be used to design aircraft fins as well as guide vanes for commercial jet engines. Improved wear and erosion resistance permit their usage in the piston liners of automotive, their intake and exhaust valves and also in brake pads. They are also intended for good thermal resistance and less coefficient of expansion[4].

IV. CONCLUSION

HMMCs have a major role in the world of material science due to its high specific strength which then replaces some alloys that offer poor properties than the HMMCs. HMMCs have higher hardness value and tensile strength compared to MMCs[4]. The literature survey highlighted many key properties and also the effect of sintering temperature and time on the HMMCs. The increase in sintering time and temperature during Powder Metallurgy process does not affect compressive strength. Increase in the percentage of reinforcement also increase properties such as hardness, impact strength, compressive strength etc. Stir casting method ensures uniform distribution of reinforcements unlike Powder metallurgy technique[15]. It is highly effective for Nano HMMCs. Addition of nanoparticles can reduce friction and increase wear resistance. Machinability of HMMCs is influenced by parameters like optimization of machining parameters, nose radius and operating conditions. Addition of graphite enhances surface roughness due to their lubricating effect[16].

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