ISSN 2581-8678, Volume II, Issue II

Properties of Metal Matrix Hybrid Composites (MMHCs): A Review

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***Abstract*- In the current scenario of engineering world, no intrinsic or monolithic materials has the ability to fulfill all the desired properties therefore, a continuous demand of such a material which shows multi-properties such as good mechanical, tribological and corrosion resistance simultaneously. There are some advance materials which can display these behaviours. So, the current study is precisely focused to review the numbers of research articles to reveal these requisite multi-properties materials and its behaviours. These materials are identified as metal matrix hybrid composites (MMHCs). Basically, the metal matrix hybrid composites comprise the matrix and two or more reinforcements. In MMHCs, Metals are used as matrix and ceramics, glass fibers etc. may be as reinforcements. This paper is exhibiting the constructive analyzed results of various mechanical, tribological and corrosion properties of several metal matrix hybrid composites and compared with its matrix.**

***Keywords*-Metal Matrix Hybrid Composites, Mechanical Properties, Tri biological property, Matrix and Reinforcements**

I. INTRODUCTION

Since, we were continually facing the problem for good quality in properties of pure or monolithic metallic materials. Then an idea of extensive development of hybrid composites came in the mind of researchers and scientist around 1970-80. Hybrid metal matrix composites (HMMCs) are engineering materials reinforced with two or more different types of reinforcement in order to take benefits of all of them which provide high degree of freedom in material's design [1]. Generally, metal matrix hybrid composites exhibit specific superior properties such as high specific stiffness, low density, strength, enhanced fatigue resistance, controlled coefficient of thermal expansion, and higher dimensional stability at high temperature [2]. The copper, zinc based alloy, magnesium and aluminum alloy's properties can be enhanced easily on addition of some ceramics reinforcement to develop a copper, zinc based alloy, magnesium and aluminum matrix hybrid composites [3-7]. In the current scenario, copper, zinc based alloy, magnesium and aluminum reinforced with different ceramics such as SiC, B_4C, TiC, ZrO_2, cBN and Al_2O_3etc. Particulates are the most common available copper, zinc based alloy, magnesium and aluminum based matrix hybrid composites. These hybrid composites possess improved properties such as elastic modulus; strength, coefficient of thermal expansion, wear resistance and high temperature property as compared to the copper, magnesium and aluminum alloy matrix. Despite the property improvement, the aluminum, copper and magnesium based composite property is not still optimized to be replaced by any copper, magnesium and aluminum product [8]. Generally, most metal matrix hybrid composites (HMMCs) are fabricated by techniques such as stir or squeeze casting, spray forming, powder metallurgy techniques and ARB process [9]. In the current investigation, detail review of mechanical, tri biological and corrosion properties of different metal matrix hybrid composites are reported and compared.

II. MATERIALS AND METHODOLOGY

TABLE I: SHOWS THE DETAIL OF COMPOSITIONS AND METHODS USED FOR THE DEVELOPMENT OF VARIOUS METAL MATRIX HYBRID COMPOSITES (MMHCs)

S. No.	Matrix	R-1	R-2	R-3	Methods
1	Pure Al	Al_2O_3	SiC	----	Anodizing followed by ARB
2	Al alloy-A356	CNTs	Al_2O_3	----	IM
3	Al alloy-AlSi12	GC	GM	----	LPI
4	Al alloy-AlSi12	SLG	GC	----	LPI
5	Pure Al	Al_2O_3	MoS_2	----	PM
6	Zinc alloy, ZA-27	SiCp	Gr	----	SC
7	Magnesium	SiC	Gr	----	PM
8	Al–Mg–Si alloy	RHA	SiC	----	DSC
9	Pure Cu	HSSS	WC	----	SC
10	Pure Cu	B_4C	WC	BN	SC
11	Pure Cu	Al_2O_3	ZrO_2	WC	SC
12	Pure Cu	WC	Al_2O_3	ZrO_2	SC

Note: *R-1, 2 and 3- Reinforcements-1, 2 and 3, ARB-Accumulative Roll Bonding, CNTs- Carbon Nano Tubes, GC-Globocer, GM-Globomet, IM- Infiltration Method, LPI- Low Pressure Infiltration, PM- Powder Metallurgy, SC- Stir Casting, DSC- Double Stir Casting,* Al_2O_3 *- Alumina, SiC – Silicon Carbide,* MoS_2 *– Molybdenum Disulfide, Gr - Graphite, RHA* - Rice Husk Ash*, HSSS – Highly Strained Stainless Steel, WC – Tungsten Carbide, BN – Boron Nitride,* B_4C *– Boron Carbide and* ZrO_2 *– Zirconia.*

TABLE II: SHOWS THE DESIGNATION OF THE VARIOUS DEVELOPED METAL MATRIX HYBRID COMPOSITES

S. No.	Designations of hybrid composites
1	MMHC-1
2	MMHC-2
3	MMHC-3
4	MMHC-4
5	MMHC-5
6	MMHC-6
7	MMHC-7
8	MMHC-8
9	MMHC-9
10	MMHC-10
11	MMHC-11
12	MMHC-12

TABLE I displays the compositional details and techniques used for the synthesis of the several metal matrix hybrid composites (MMHCs). There are different metals are selected for matrix such as pure Al, Al alloys, zinc alloy, pure Mg, magnesium alloy and pure copper. However, the various ceramic materials like – alumina(Al_2O_3), tungsten carbide (WC), zirconia(ZrO_2), boron carbide (B_4C), boron nitride (BN), silicon carbide (SiC) and other materials such as highly strained stainless steel (HSSS), molybdenum disulfide (MoS_2), carbon nanotubes (CNTs), graphite (Gr) etc. are utilized as reinforcements. There are various methodologies or techniques used for reinforcing or adding of these reinforcements in the metal matrix such as anodizing followed by ARB, infiltration method, low pressure infiltration, powder metallurgy, stir casting and double stir casting. After the development of the hybrid composites by various routes, now they are ready for the different characterizations and results for various properties like- mechanical properties, tri biological properties and corrosion properties etc. TABLE II displays the designation of the various developed metal matrix hybrid composites by different techniques.

III. RESULTS & DISCUSSION

A. *Tensile property of MMHCs*

TABLE III: SHOWS THE TENSILE STRENGTH OF VARIOUS MMHCs AND ITS MATRICES

Matrix	Tensile Strength, MPa	MMHCs	Tensile Strength, Mpa
Pure Al	91.4	MMHC-1	284.4
Al alloy-A356	~83	MMHC-2	~175
Al alloy-AlSi12	Nil	MMHC-3	Nil
Al alloy-AlSi12	Nil	MMHC-4	Nil
Pure Al	Nil	MMHC-5	Nil
Zinc alloy, ZA-27	Nil	MMHC-6	Nil
Magnesium	Nil	MMHC-7	Nil
Al–Mg–Si alloy	Nil	MMHC-8	Nil
Pure Cu	~245	MMHC-9	~430
Pure Cu	~240	MMHC-10	~360
Pure Cu	~239	MMHC-11	~405
Pure Cu	Nil	MMHC-12	Nil

Note: The entire test was not performed at the same conditions

TABLE III depicts the detail of tensile strength of developed various MMHCs and its matrices. Tensile property of materials was evaluated on universal testing machine. From the table, it is very clear that MMHCs have higher tensile strength as compared to its matrices. It is attributed to the addition of harder ceramics and other materials into the softer matrices which may have the good interfacial bonding between the reinforcements and matrices [4-5, 7]. However, there are some variations in tensile strength of the MMHCs observed as the metal matrix and reinforcements' vary. It is found that the copper based hybrid composites have better tensile strength as compared to aluminum and its alloy based hybrid composites [10]. It may be due to the higher density and mechanical strength of copper as compared to aluminum and copper may have better interfacial bonding between with reinforcements compared to aluminum and its alloy.

B. *Hardness property of MMHCs*

TABLE IV: SHOWS THE VICKERS HARDNESS OF VARIOUS MMHCs AND ITS MATRICES

Matrix	Vickers Hardness, HV	MMHCs	Vickers Hardness, HV
Pure Al	Nil	MMHC-1	Nil
Al alloy-A356	Nil	MMHC-2	Nil
Al alloy-AlSi12	Nil	MMHC-3	Nil
Al alloy-AlSi12	Nil	MMHC-4	Nil
Pure Al	Nil	MMHC-5	Nil
Zinc alloy, ZA-27	~100	MMHC-6	~110
Magnesium	~27	MMHC-7	~83
Al–Mg–Si alloy	Nil	MMHC-8	Nil
Pure Cu	~59	MMHC-9	~104
Pure Cu	~75	MMHC-10	~180
Pure Cu	Nil	MMHC-11	Nil
Pure Cu	~76	MMHC-12	~160

Note: The entire test was not performed at the same conditions

TABLE IV shows the Vickers hardness of the MMHCs and its matrices was performed on Vickers hardness tester. Table reports very precisely that the MMHCs have higher hardness as compared with its matrices. This improvement in hardness of MMHCs is attributed to the addition of harder ceramic materials in the softer matrices. So when the load applied to them then the plastic deformation of softer matrix will start first and the load is transfer from softer matrix to harder ceramic materials which resist further deformation of the materials. It may also due to the decrease in porosity of the materials when reinforcements added to matrices. The elastic modulus and thermal mismatch between reinforcements and matrices may also play vital role in the hardness improvement of the hybrid composites [5, 6]. On addition of reinforcement in matrices there is major probability of reducing in crystallite size of materials and this reduced crystallite size improve the strength. It is also observed that copper based hybrid composites have higher hardness as compared others.

C. Tribiological property of MMHCs

TABLE V displays the volume loss of developed various MMHCs and its matrices under dry sliding conditions. It is very interesting that almost all the developed hybrid composites show lower cumulative volume loss as compared to its matrices. It may be attributed to the addition of harder ceramics reinforcements in softer matrix. When, the normal load applied to the pin the early exposure of this harder reinforcement start carrying the load for longer time with very less volume loss of it. In addition to this less volume loss in MMHCs, it is due to its higher hardness also as reported in Table IV because Archard's law of wear say if the hardness of materials is higher that will show lower wear volume [11-13]. However there are two cases of hybrid composites such as MMHC-3 and 4 reveals higher cumulative volume loss as compared to its matrices. It may be due the poor strength of the hybrid composite due to the development of higher porosity on addition of the reinforcement in the matrices. MMHC-7 exhibits lower cumulative volume loss compared with its matrix, it is attributed to the addition of graphite which acts as solid lubricants so during sliding against disk, and it come out and spread partially over the surface of counter disk [14].

TABLE V: SHOWS THE CUMULATIVE VOLUME LOSS OF VARIOUS MMHCs AND ITS MATRICES UNDER DRY SLIDING CONDITIONS

Matrix	**Cumulative Volume loss, $mm^3 \times 10^{-3}$**	**MMHCs**	**Cumulative Volume loss, $mm^3 \times 10^{-3}$**
Pure Al	Nil	MMHC-1	Nil
Al alloy-A356	Nil	MMHC-2	Nil
Al alloy-AlSi12	2.25	MMHC-3	9
Al alloy-AlSi12	2.25	MMHC-4	13.5
Pure Al	Nil	MMHC-5	Nil
Zinc alloy, ZA-27	~9.5	MMHC-6	~3.1
Magnesium	~7.192	MMHC-7	~3.263
Al–Mg–Si alloy	Nil	MMHC-8	Nil
Pure Cu	Nil	MMHC-9	Nil
Pure Cu	Nil	MMHC-10	Nil
Pure Cu	Nil	MMHC-11	Nil
Pure Cu	~5.2	MMHC-12	~2.1

Note: The entire test was not performed at the same conditions

Pin-on-disk apparatus was used to characterize the cumulative volume loss of MMHCs and matrices under dry sliding condition. In this test, pin was made up of hybrid materials and matrices which slide against the harder counter disk rotating at definite r.p.m under dry condition. Among all the hybrid composites, copper based hybrid composite (MMHC-12) shows least cumulative volume loss.

D. Corrosion Property of MMHCs

TABLE VI: CORROSION POTENTIALS AND CORROSION CURRENT DENSITIES OF THE DEVELOPED MMHC-8

Materials	$-E_{corr}$(V)	I_{corr} ($\mu A/cm^2$)
Al-Mg-Si alloy	807.772	0.819
MMHC-8	710.055	0.415

TABLE VII
CORROSION POTENTIALS AND CORROSION CURRENT DENSITIES OF THE DEVELOPED MMHC-9

Materials	$-E_{corr}$(V vs Ag/Agcl)	I_{corr} ($\mu A/cm^2$)
Pure Cu	0.072 ± 0.006	27.54 ± 2.62
MMHC-9	0.089 ± 0.003	1.52 ± 0.17

Corrosion test was not performed for all the developed MMHCs. Only MMHC-8 and MMHC-9 were characterized for corrosion behaviour. Al-Mg-Si alloy was used as matrix in the development of MMHC-8 however; monolithic copper was used as matrix in MMHC-9 development. The corrosion properties of MMHC-8 were investigated in 3.5% NaCl solution at room temperature (25 ◦C) using potentiodynamic polarization electrochemical methods. [15]. However the corrosion properties of MMHC-9 were performed by electrochemical test on the samples (area-1 cm2) after 1 h immersion in

0.1M NaCl at room temperature(25 ± 2 °C). [7]. From both the Table VI and VII, it is very clear that the hybrid composites MMHC-8 and 9 shows a lesser corrosion current density as compared to its matrices which means a low corrosion current density of materials reflects good corrosion resistance [7, 15]. Therefore, it can be say that the corrosion resistance of any materials can be improve by addition of hybrid reinforcements such as 'RHA+SiC' and 'HSSS+WC' etc. in the materials.

III. CONCLUSION

In the current investigation, it is observed that the mechanical, tribiological and corrosion properties of the metal matrix hybrid composites (MMHCs) developed by any processes shows better results as compared to its matrices. So, in the current scenario the MMHCs can be most appropriate engineering materials for various applications in the fields of aerospace, automobile, railways, marines etc.

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