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The Physical Properties of Hybrid Metal Matrix Composites Made of Al6061, Silicon Carbide,and Boron Carbide

H C Chittappa*[1], Preetham T*[1], Venkatesh N*[2], Ananda G K*[2]

*[1]*Professor, Department of Mechanical Engineering, University Visvesvaraya College ofEnginering, Bengaluru- 560001 India*

*[1] *Research Scholar, Department of Mechanical Engineering, University Visvesvaraya College of Enginering, Bengaluru- 560001 India*

*[2] *Assistant Professor, Department of Mechanical Engineering, University Visvesvaraya College of Enginering, Bengaluru- 560001 India*

Abstract:-In demand of today's and future Al alloys are the best suitable materials for engineering applications. The development of AMCs needs new materials able to match by increasing strength in the place of conventional materials. The present article contains Al6061base matrix and reinforcement used as Silica carbide (SiC), boron carbide (B4C) with different composition percentages (5, 10, 15), and balancing of B4C (5).The Al hybrid composites are fabricated via stir die-casting process. Mechanical properties are investigated as per ASTM standards procedure incorporating with the variation of specimen's samples. The results showed that higher thermal conductivity, tensile strength, hardness indention, and lower coefficient of thermal expansion are obtained at SM-4(Al-15SiC-5B4C) of hybrid composites. However, the experimental data of thermal conductivity and coefficient of thermal expansion are compared with theoretical data by Rule of mixtures or turners model.

Keywords:*Aluminium matrix, boron carbide, silica carbide, thermal conductivity, thermal expansion;*

1.Introduction

The lightweight composite materials exhibit the properties like higher strength, lower thermal expansion, higher thermal conductivity, and improvement in modulus of elasticity [1]. The Al hybrid composites are playing a vital role in automobiles industry usage and aerospace components. The addition of reinforcement in the matrix materials contributes the higher performance in AMCs. Hybrid Composites have been widely used in hospital industries, automobiles, and aerospace [2],[3],[4]. In the coming years, intensive materials research was carried out on extensive activities in ceramics reinforcements. Innovative materials open up unlimited possibilities for modern materials science and development, characteristics of AMCs can be designed as composite materials, custom made, dependent on the application [5]. Standards specific demands, if the property profile of conventional materials either does not reach or increased in materials group becomes interesting for use as constructional and functional materials. Moreover, the technology of AMCs competes with other modern materials technologies, for example, powder metallurgy [6]. When there is a reasonable cost performance relationship in the component production with realized the advantages of modern materials technology [7]. To understanding particle reinforcement light-weight composites, identify some of the key factors which need to be controlled may be specific to the mode of processing. Composite materials mainly depend on the shape, size of constituents, their structural arrangement, and distribution of reinforced phase in a matrix [8],[9],[10]. The Al hybrid alloys are widespread in transportation engineering applications cause effects of their higher strength to weight ratio. For the class of lightweight composition of reinforcement in matrix phase systems, mixing of reinforcements on AL hybrids matrix could be in the form of particulate, discontinuous, continuous, and whiskers in nature [11],[12],[13]. Mechanical properties of Al hybrids composites can be tailored to the demands of different industrial applications of the matrix, processing route, and reinforcement. The worldwide upsurge in AMCs research and development activities is focusing on main n Al alloys [14]. A unique combination of Al matrix composition produces properties like low density, wear resistance, and excellent mechanical properties. In avionics and aerospace applications, the Al hybrids composite exhibits thermal expansion which can be tailored down to zero [15],[16],[17]. They explained the Al metal matrix composites research and development activities with particulate emphasis on as-cast composites. The higher thermal conductivity by EMC for micro-electronic encapsulation had concluded [18]. Enhancement of thermal conductivity of polymer matrix composites in solid loading of Al nitrides in epoxy resins. For the determinations of conductivity for anisotropy of polymer solids under large strains. The methods of describing low electric conductivity and lower thermal expansion were approached [19],[20]. In past years, the researchers are concentrated on LM13/Graphite, LM13/Zirconium, and LM13/Quartz was studied [21],[22],[23]. Dispersed porosity or micro shrinkage in the Al matrix composites can be minimized by the judicious location of chills. The microstructure of the hybrid composites does significantly affect strength, bonding between the matrix and reinforcement phase. Tribological properties of Al HMMCs had successfully attained by introducing ceramics particles such as B4C, Al_2O_3, SiC, and TiC using different routes such as in-situ, squeeze casting, stir-casting, and powder metallurgy. Microstructural of chill cast Al-B4C composites exhibit an effect of micro-hardness were studied[24],[25]. Investigated the effect of reinforcement and chilling on hardness, strength, and wear behavior of Al-based hybrid matrix incorporated with reinforcement of kaolinite, and carbon particulate. They discussed that chilled HMMCs with Al_2SiO_5-9%/C-3% dispersion content provided be best in enhancing the wear and mechanical properties. By powder metallurgy techniques, the hybrid composites influencing on mechanical and microstructural of Al2024/5wt%SiC with X wt% graphite(X=5 and 10). They have reported on the influencing E-glass fiber reinforcing and SiC particulate via fabricated route. They discovered hybrid composites of Al alloys reinforced with graphite and alumina by the stir casting process [25],[26],[27]. From this literature study, the main objective is to develop new hybrid Al composites with different weight percentages SiC(5,10,15) and B4C(5). To understand the microstructure and mechanical behavior of hybrid composite materials (**See Fig.1**) [28],[29].

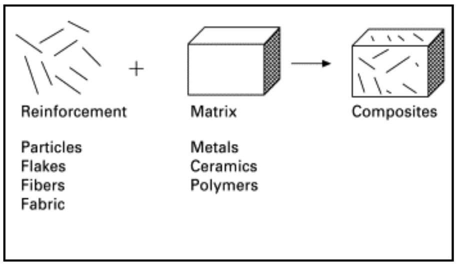


Fig.1 Schematic view of matrix and reinforcement phase

2. Methodology

The selection of lightweight Al6061 and different weight percentages of silica carbide (5, 10, 15) with boron carbide (5). The process of new hybrid composites via material selection, fabricated route, preparation of samples, and testing of physical properties as per ASTM standards.

2.1 Materials Selection

In this research, the Al 6061 alloys series and different weight percentage of reinforcement silicon carbide (5, 10,15) with balancing (5) of boron carbide. The chemical and physical properties of Al alloys and reinforcement are shown in **Table 1, Table 2, and Table 3** respectively.

Table.1 Chemical composition of Al6061 alloys

Elements	Percentage (%)
Al	89
Mg	6
Si	3
Cu	1.5
Zn	0.5

2.2 Stir-casting Process

The liquid metallurgy techniques via stir-casting process were carried out for fabricating Al hybrid metal matrix composites (HMMCs). The specimen samples are prepared by varying the volume fraction and reinforcement materials. For the experimental constraints, our studies are limited adding reinforcement of SiC to 20%, and B4C was limt to 5% beyond usage of B4C exposes to brittle nature of materials (See Table.4). According to rule of mixtures, the density of composites can be related by formula [28].

$$\rho_c = \rho_m v_m + \rho_{r1} v_{r1} + \rho_{r2} v_2 \tag{1}$$

Here, ρ_c be the composite density (kg/m^3); V be the volume fraction (m^3); ρbe the density (kg/m^3); (m, r) be the subscripts of matrix and reinforcements;

Table.2 Chemical composition of reinforcements

Elements	Silicon carbide (%)	Boron carbide (%)
SiC	98.5	….
B4C	----	99.5
Si	0.3	…..
Fe	0.08	….
Al	0.1	….
C	0.3	0.5

Table.3 Properties of Al6061 alloys, Silicon carbide, and Boron carbide

Particulates	Al6061	SiC	B4C
Density(kg/m^3)	2.70	3.56	2.52
Melting point (^{0}C)	588	1970	2350
Tensile strength (MPa)	310	1270	456
Elastic modulus(GPa)	68.5	127	424
Poisson's ratio	0.33	0.37	0.41
Thermal conductivity(w/m-k)	167	18.5	35.45
Thermal expansion (10^{-6}/^{0}C)	23.2	8.5	5.00

Table.4 Composite composition designated in volumetric percentages

Particulars	Al6061 alloys	SiC	B4C
SM-1	100%(1000g)	0	0
SM-2	90%(900g)	5%(50g)	5%(50g)
SM-3	85%(850g)	10%(100g)	5%(50g)
SM-4	80%(800g)	15%(150g)	5%(50g)

The processes of de-casting were preheated in the furnace for 500 to 600^{0}C for three hours respectively. The Al6061 wads melts in crucible, and then pour to the preheated reinforcement in matrix phase. Due to remove oxidization, adding 1% degassed tablet in the crucible to improve the wettability of matrix, and reinforcement phase. In order to proper mixing, stirrer was placed at height of 1/4th of crucible, and maintained speed of

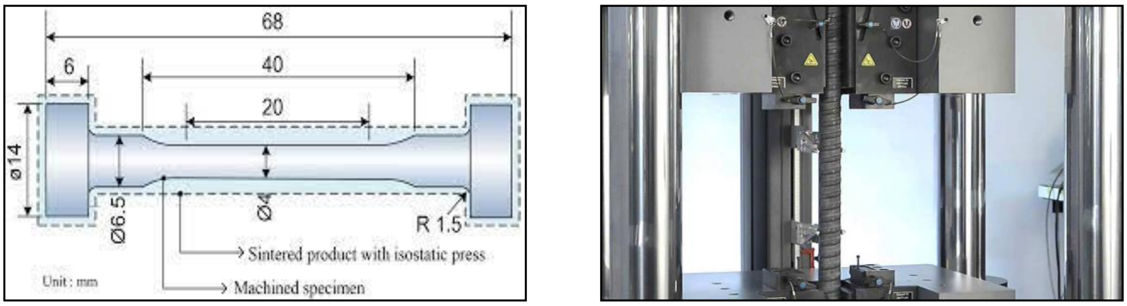
400rpm for 15mins. A stirrer is made up of brass (blades of stirrer) material welded against the stainless steel (rod). Proper mixing of the reinforcement, the stirrer blades such way that die-size (L=300mm,d=10mm,L_b=20mm) and placed into 120^0 angle to the stainless steel rod [27],[28],[29]. To study the distribution of reinforcement in the matrix phase, microstructure of specimens, for which prepared the specimen samples (**Fig.2a, 2b**).The theoretical data were estimated by principle of Rule of mixtures (ROM), and turner's model. The experimental results of coefficient of thermal expansion, thermal conductivity, and compared with theoretical study.They explained the Al metal matrix composites research and development activities with particulate emphasis on as-cast composites. The higher thermal conductivity by EMC for micro-electronic encapsulation had concluded.From this literature study, the main objective is to develop new hybrid Al composites with different weight percentages SiC(5,10,15) and B4C(5). To understand the microstructure and mechanical behavior of hybrid composite materials

(a) (b)

Fig.2 (a) Schematic view of stirrer speed; (b) die-casting process

2.3Testing of Tensile Strength

The major engineering problems are solved by ultimate tensile strength or it's the ability of material to withstand before fracture. The specimen samples are prepared with four different weight fraction of composites. To determine the ultimate tensile strength, the specimen samples are prepared as per ASTM standards[30] (**Fig.3a,3b**).

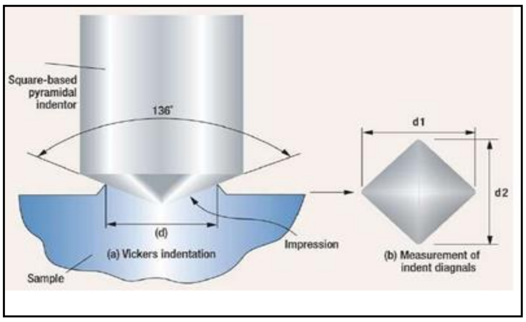


(a) (b)

Fig.3 (a) Tensile specimen standard ;(b) Tensile testing machine(ASTM E8)

2.4 Testing of Hardness

A Rockwell harness testing machine were used to determine, the forces which pointed into the surface and measures increasing in penetration, as the penetration in terms of micrometers with leads samples deforms or moves, significant errors may arises [31]. The intenders pressed with the pre-force to penetration (h_1) in the samples to be tested. Its defines the reference level (h_1) for subsequent measurement of the residual indentation depth (h). The additional test force is applied for a dwell period defined in accordance with standards indentations penetration into the specimens to a maximum indentation depth (**Fig.4a, 4b**).



(a)

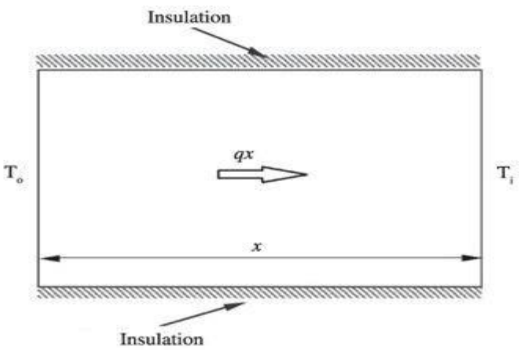
(b)

Fig.4 (a) Hardness specimen standard ;(b) Rockwell testing machine (ASTM E18-20)

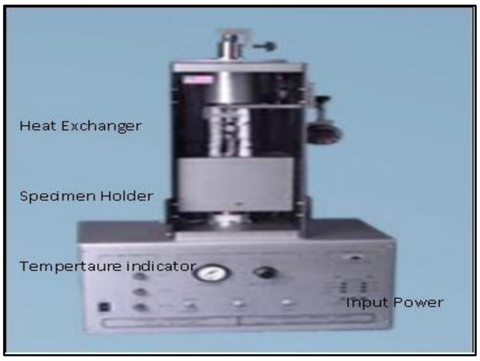
After the test force is removed, the indentation moves up by the elastic proportion of the penetration depth in total test force and remains at the level of the residual indentation depth (h-expressed in units of 0.002 or 0.001mm). The differential depth (differences in indentation depth before and stirrer application of the total test force). The resultant of Rockwell hardness (HR) is calculated using the residual indentation depth (h) and a formula defined in the standard, taking account of the applied Rockwell scale.

2.5Testing of Thermal Conductivity

The specimen dimensions are diameter 25mm and 80mm length as per ASTM (1225-99) standards. From the principal of Fourier law of conduction under steady state are operated conditions with un-directional heat flow. Before testing the specimen were cleaned by alcohol and then by acetone to remove dust particles[32]. The samples are mounted on the testing column and the temperature measured from room temperature (**Fig.5a, 5b**).



(a)

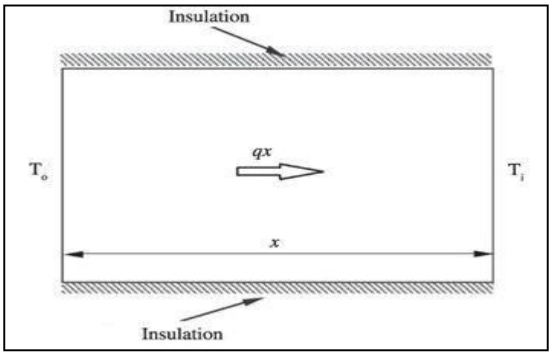


(b)

Fig.5 (a) Schematic view of heat flow direction ;(b) Testing g machine of thermal conductivity

2.6 Testing of Thermal Expansion

In this test, a coefficient of thermal expansion measured (Model TMA400, ASTM 831-04) equipment thermo-mechanical analyzer. The test was carried out in central power research institute, Bengaluru and standard sample size diameter 8mm and 12mm length [33]. The temperatures are maintained from 50^0 to 500^0C at 5^0C /mins set-up and supply nitrogen inert gas 50ml/mins for heated specimen instantly (**Fig.6a, 6b**). From the experimental data were obtained in the form of PLC (Percentage linear change) versus temperature rise with



interval of 100^0C.

(a) (b)

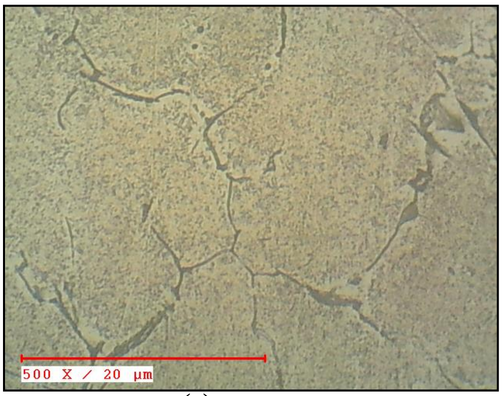
Fig.6 (a) Standard specimen of expansion ;(b) Testing machine of thermo-mechanical analyzer(TMA400)

3. Result and Discussion

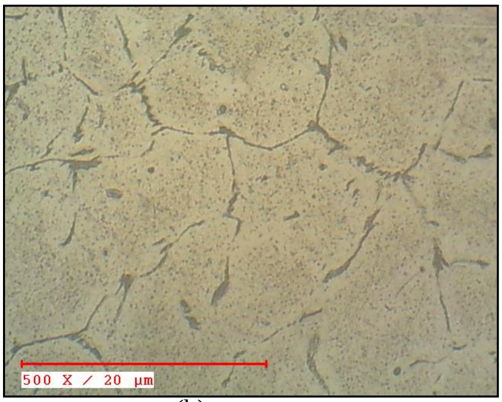
After attesting the samples, the experimental data were recorded and discussion of data in terms measuring quantities. The behavior of microstructure and mechanical characteristics such as tensile strength, hardness, thermal conductivity, and coefficient of thermal expansion.

3.1 Effect of Microstructure Behavior

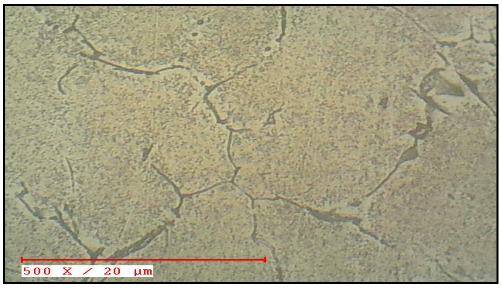
The Al6061 hybrid composite with different weight fractions silica carbide (5, 10, 15) and boron carbide (5). The small piece of sample specimen is molded (Bakelite powder). Using the emery sheets grade-120, 220, 320, 400, 600, 8000, 1000 are used to clean the surface of samples [34],[35],[36]. Microstructure characteristics were tested as per ASTM standards with particle size of 20µm with magnification of 500X. The samples SM-3 (Al6061-10SiC-5B4C) are well bondage between matrix and reinforcement phase(**Fig.7a, 7b, 7c, 7d**). Compared to other specimen samples, it observed that fine coarse aggregates are well binding between grain size structures [34].



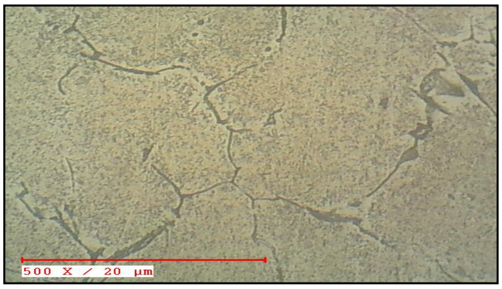
(a)



(b)



(c)



(d)

Fig.7 (a) SM-1 of Al6061 alloys matrix phase ;(b) SM-2 of Al6061-5SiC-5B4C;(c) SM-3 of Al6061-10SiC-5B4C;(d)SM-4 of Al6061-15SiC-5B4C

3.2Effect of Tensile Strength

In this test, the Al6061 hybrids composites were tested with different weight fraction of reinforcement. The **Fig.8** shows that higher tensile strength has been reached at SM-4(Al6061-15SiC-5B4C) and lower strength is obtained at SM-1 (Al6061 alloys) without adding reinforcement phase.Due to addition carbon particles of reinforcement in matrix phase and it leads the increases the strength of composite materials. It's observed that increasing of tensile strength adding reinforcements may play vital role in Al hybrid composite materials[37],[38].

3.3Effect of Thermal Conductivity

The rate of heat transfer is directly proportional to the surface area; change in temperature, and inversely to proportion to length of samples referred as Fourier law of conduction [41].

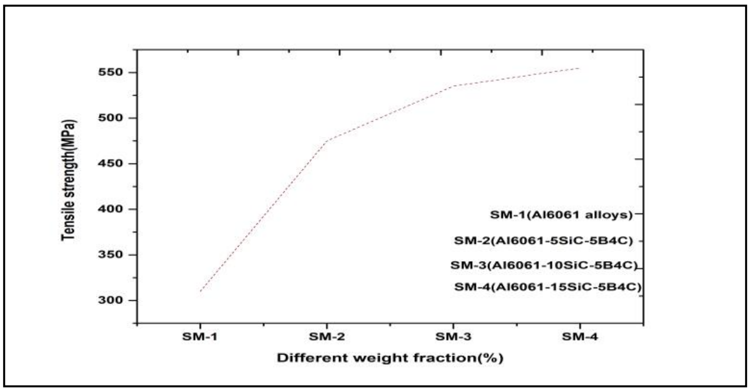


Fig.8 Tensile strength versus different weight fraction

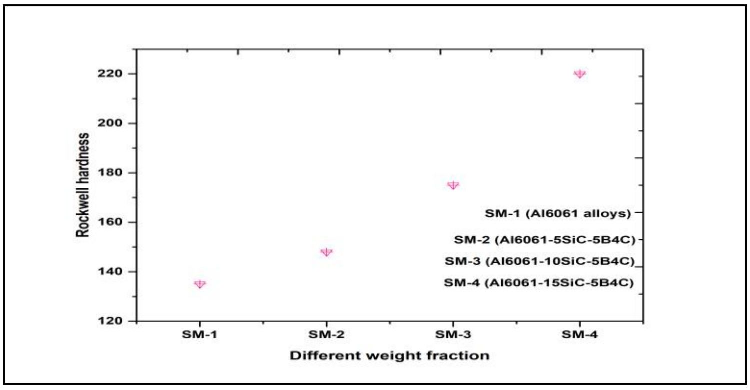


Fig.9 Rockwell hardness versus different weight fraction

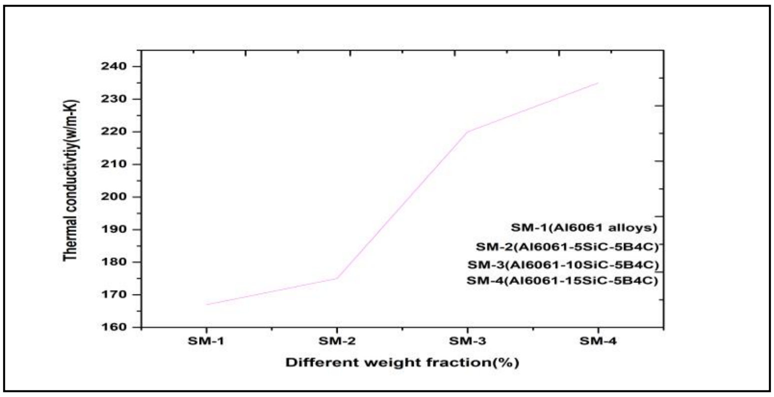


Fig.10 Thermal conductivity versus different weight fraction

In this results, the Al hybrid composites exhibits excellent conductivity with additions of weight fractions. The **Fig.10** shows that base matrix phase(SM-1) is obtained at 167w/m-K without adding reinforcement phase. It observed that gradually increases conductivity while addition of different weight fractions. The higher conductivity has been found at SM-4(Al6061-15SiC-5B4C) and increasing of heat transfer is mainly depends on carbide elements in reinforcement phase [42].

3.4Effect of Hardness

The Rockwell hardness test was carried out to study the Al hybrid composite materials by varying reinforcements in matrix phase with addition of carbide element particles. The hardness test exhibits significant role in measuring the indentation of depth in terms and its represents the strength of materials. **Fig.9** shows that higher hardness at SM-4 with addition 15% of silica carbide and 5% of boron carbide (RHN220). The SM-2(Al6061-5SiC-5B4C) has found the lower value of hardness of the materials (RHN137) with adding of less amount of carbon particle in matrix phase. This leads the more hardness of the materials becomes higher strength due to combination of hybrid reinforcements [39],[40].

3.5 Effect of Thermal Expansion

The ratio of change in length to the original length of samples refers as strain. The coefficient of thermal expansion withstands temperature mainly depends on size of specimens, dispersed reinforcement in matrix phase, and selection of Al composite materials. **Fig.11** shows that lower expansion of Al hybrid materials exhibits at SM-3 (Al6061-10SiC-5B4C) and gradually increases at SM-4(Al6061-15SiC-5B4C). Due to temperature rise, the Al hybrid composite contains silicon, carbon, magnesium particulates in reinforcement phase [43].

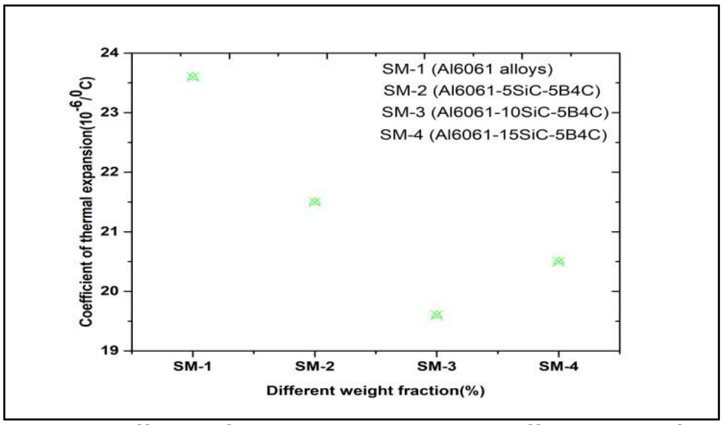


Fig.11 Coefficient of thermal expansion versus different weight fraction

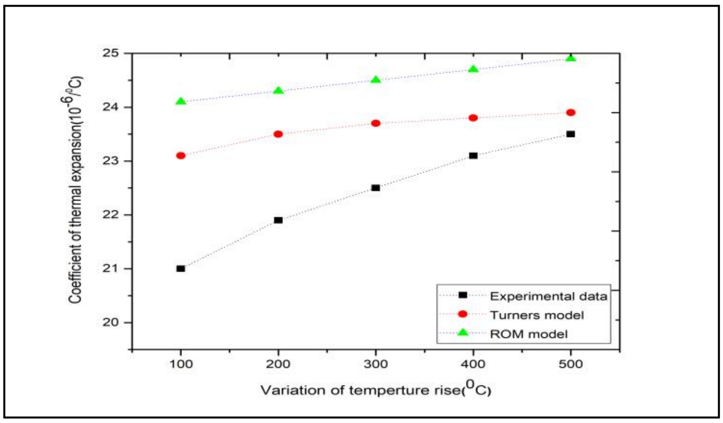


Fig.12 Temperature rise is function of thermal expansion

3.6 Comparison Study of Experimental with Theoretical data

The theoretical data were estimated by principle of Rule of mixtures (ROM), and turner's model. The experimental results of coefficient of thermal expansion, thermal conductivity, and compared with theoretical study.

3.6.1 Coefficient of Thermal Expansion

The comparison studies of coefficient of thermal expansion are studied with theoretical data by Rule of mixtures, and turner's model. The **Fig.12** shows that variation of temperature of samples versus coefficient of thermal expansion [44],[45].

From the percentage linear change (PLC), the Al hybrid composites were tested between 100 to 500^{0}C with considered by room temperature. The experimental results of CTE are well beyond the limit as compared with Rule of mixtures (ROM), Turners model [46].

3.6.2 Effective Thermal Conductivity

The guarded heat flow measurement apparatus were used to test the experimental data of thermal conductivity. Due to addition of reinforcement in matrix phase, the thermal conductivity is directly proportional to the surface area of Al hybrid composite materials. The **Fig.13** shows that thermal conductivity (SM-1, SM-2, SM-3, SM-4) of experimental data was well matched with turner's model, rule of mixtures of theoretical data [47].

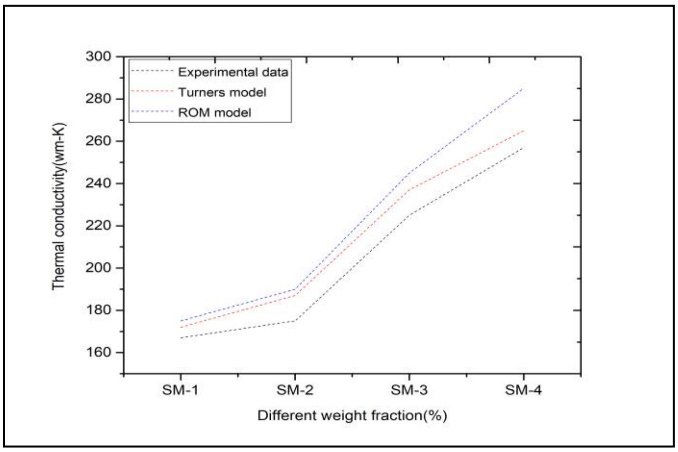


Fig.13 Experimental conductivity versus theoretical data

$$\frac{\Delta L}{L_o} = \alpha.\Delta T \tag{2}$$

Here, ΔL be the change in length (mm); L_o be the original length of samples(mm);α be the coefficient of thermal expansion($10^{-6}/^oC$);ΔT be the change in temperature (^oC) [48],[49];

$$K = \frac{QxL}{Ax\Delta T} \quad (3)$$

Here, Q be the rate of heat transfer (w);A be the surface area (m^2);L be the length of samples (mm);ΔT be the change in temperature (^oC) [50];

4. Conclusion

The results of Al6061 hybrid composite materials with adding of reinforcement of silica carbide and boron carbide were developed via stir-casting process and samples are tested as per ASTM standards. The following points were drawn from the testing results.

- The sample of SM-4 (Al6061-15SiC-5B4C) is well bondage between matrix and reinforcement phase with comparing other samples of SM-1, SM-2. They exhibit fine coarse aggregates between composite structures due to addition of silica carbide and boron carbide.
- The higher tensile strength has been found at SM-4(555MPa) and lower strength obtained at SM-1(320MPa) incorporated with pure Al6061 alloys matrix.
- The Rockwell hardness of sample SM-4 (RHN220) has been reached higher indentation and lower indentation is obtained at SM-1(RHN137) without adding reinforcement in matrix phase.
- The higher rate of heat transfer exhibits at SM-4(235w/m-K) and gradually decreases the conductivity of Al6061 alloys of matrix phase.
- The lower coefficient of thermal expansion has found that at SM-3($19.5x10^{-6}/^0C$) and small amount increments of expansion is reached at SM-4($21.5x10^{-6}/^0C$).
- Furthermore, the comparison of thermal expansion and thermal conductivity of experimental data were well matched with theoretical data by Turners model or ROM model.

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