EFFECT OF HEAT TREATMENT ON WEAR BEHAVIOR OF ALUMINIUM BASED HYBRID COMPOSITES UNDER DRY SLIDING MOTION

Ranganatha S R[1], Shantharaja M [2]
1 Asst.Prof, Department of mechanical engineering, DBIT, Bangalore, Karnataka, India,
2 Asst.Prof, Department of mechanical engineering, UVCE, Bangalore, Karnataka, India.

Abstract: This present work deals with the fabrication of Al 2014 reinforced with boron carbide and short copper Basalt fiber based Hybrid metal matrix composite through stir casting process and study the wear behavior of both as cast and heat treated specimens. The microstructure of this composite was examined and observed uniform distribution of reinforced particles in the matrix. Wear experiments were conducted on pin-on-disc tester with three process parameters such as applied load, speed and sliding distance; each varied for three levels. Loads of 20 N, 40 N, 60 N; speed of 400rpm,600rpm,800rpm and sliding distance distances of 314 m, 472 m, 628 m were considered for evaluating the wear behavior of hybrid composite. Result shows that effect of both Boron carbide and Short copper coated basalt fiber composites shows good wear resistance for all composites and also observed heat treated specimens 30 to 45 % better wear resistance as compared to as cast specimens. It was observed that, severe delamination occurred as applied load increased from 40 N to 60 N. This wear analysis can be utilized to replace the conventional aircraft materials with aluminium Hybrid metal matrix heat treated composites having better wear characteristics.

***Index Terms* - AA2014, HAMCs, Boron carbide, Basalt fiber, pin-on disc, Coatings, Stir casting and wear rate.**

1. INTRODUCTION:

In recent years aluminium matrix hybrid composites (HAMCs) are gaining widespread popularity in several technological sectors owing to their excellent corrosion and wear resistance, higher fatigue life, good high temperature oxidation resistance in addition to being light in weight when compared with conventional alloys. general engineering materials used in the field automobile, aircraft and marine applications have limitations in achieving optimum levels of strength, stiffness, density, toughness and wear resistance. The composite material and heat treatment process is to tailor the material properties according to their requirements. These composites were artistic with good wear properties due to the presence of hard ceramic reinforcements. Aluminium Metal Matrix Composites (AMMCs) gained importance due to their enhanced the tribological properties that replaces their monolithic counterparts primarily in automotive, aerospace, marine and energy applications [1]. Several studies have shown that fiber reinforced composites are more proficient than other types of composites. Currently, the typical ceramic fibers are reinforced with metal matrix for industrial and commercial applications. This research is a contribution to efforts aimed at the development of Aluminum matrix Hybrid composites (AMHCs) with high performance indices at low cost. The good performance in service and consequent high demand for AMHCs is attributed to its excellent combination of properties such as high specific strength and stiffness, low thermal coefficient of expansion, good wear, corrosion and high temperature resistance among others. Although these fibers offer superior properties (high temperature stability, low thermal conductivity, low heat storage etc.), their production cost is high. [2-4]. Siddhartha Prabhakar et al investigated the tribological behavior of LM 14 aluminium/B4C composite under dry sliding motion and they conclude aluminium alloy matrix composite reinforced with 5 wt% of B_4C particles was successfully fabricated through stir casting route and observed Uniform distribution of particles in the matrix by using SEM and also analyzed experimentally wear rate and coefficient of friction has a direct relation with the load, whereas inverse with the sliding speed and distance[5]. V.C. Uvaraja et al. [6] studied wear behavior of Al6061 and Al7075 alloy with SiC and B4C reinforcements. From the results obtained from the experiment it is concluded that the enhanced wear rate and hardness of Al7075 hybrid metal matrix composites was found as compared to Al6061 hybrid metal matrix composites. Ning li et al[7] study the effect of heat treatment on the aluminium-silicon carbide composites then observed due to addition of SiCp, the shape of eutectic silicon was changed to a fine acicular or short stick or even a granular-like shape, and the phase was also distributed uniformly. Therefore, the interface bonding strength of the secondary phase with the matrix was reinforced, the mechanical and wear resistance property was improved, and the wear rate was decreased. Treated by T6, the eutectic silicon was spheroidal in shape, and some light grey √ phases were precipitated. As a result, the wear resistance property was improved.

G L Rajesh et al studied the wear properties of the Al 6061 composites at room temperature for normal load of 49.05N with varying sliding distance ranging from 3.34m/s to 10m/s and sliding distance of 565.4m/s followed by worn surfaces morphology through optical microscopy and they observed minimum wear rate at maximum wt % of boron carbide[8]. Shantharaja M et al studied the wear behavior of boron carbide and short copper coated short basalt fiber reinforced on Al 2014 based hybrid composite by using pin on disc tester for three different wear parameters such as Loads of 20 N, 40 N, 60 N; speed of 400 rpm, 600 rpm, 800rpm and sliding distance distances of 314 m, 472 m, 628 m. Result from the investigation increases in the weight percentage of boron carbide (B4C) and copper coated short basalt fiber in Al2014 there is an increase in wear resistance. At maximum of 8% boron carbide and 8% copper coated short basalt fiber shows lower wear rate of the composites[9]

2. **Materials used**

2.1 Matrix Materials:

AA2014 was used as matrix material with its compositions as shown in table 1. The main alloying element is Copper with Manganese and silicon. AA2014 alloy is aluminium based alloy often used in the aerospace industry and is the second most popular of the 2000-series aluminum alloys, after 2024 aluminum alloy. It is commonly extruded and forged. The corrosion resistance of this alloy is particularly poor.

Table 2.1: Composition of AA2014

Elements	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn	Ti+Zn
Composition In %	Remainder	0.1	3.9 – 5	0.7	0.2-0.8	0.4-1.2	0.5-1.2	0.15	0.25	0.25

3. **Reinforcement Materials**

3.1 Reinforcement 1: Boron Carbide

Boron carbide (B_4C) is extremely hard boron – carbon ceramic and covalent material used in tank armor, bulletproof vests, engine sabotage powders, as well as numerous industrial applications.

The ability of boron carbide to absorb neutrons without forming long-lived radio nuclides makes it attractive as an absorbent for neutron radiation arising in nuclear power plants and from anti-personnel neutron bombs. Nuclear applications of boron carbide include shielding, control rod and shut down pellets. Within control rods, Boron carbide is often powdered, to increase its surface area.

3.2 Reinforcement 2: Basalt fiber

Basalt fiber is a relative newcomer to fiber reinforced polymers (FRPs) and structural composites. It has a similar chemical composition as glass fiber, but has better strength characteristics, and unlike most glass fiber is highly resistant to alkaline, acidic and salt attack making it a good candidate for concrete, bridge and shoreline structures.

Compared to carbon and aramid fiber, it has the features of the wider application temperature range -269° C to +650° C, higher oxidation resistance, higher radiation resistance, higher compression strength, and higher shear strength.

3.2.1 Chemical composition

Compounds	SiO_2	TiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	K_2O	MnO
(%)	51.55	2.67	12.95	9.21	4.62	10.68	5.40	1.99	0.28

4. **Experimental work**

4.1 Fabrication of hybrid composites:

The preparation of hybrid metal matrix composite used in this investigation was fabricated by using stir casting method, it is also called as liquid state method It consists muffle furnace, graphite crucible and arrangement of mechanical stirrer. Here pure aluminium-2014 alloy was commercially prepared heated in a muffle furnace up to 750-800˚C. During melting aluminium alloy hexachloroethane pallets were added to remove the atmosphere gases particularly hydrogen. Suppose if these gases are not removed it will affect the casting. After that measured quantity preheated boron carbide and coated short basalt fiber were added at a rate of 10-30 g/min into the melt and mixed with help of stirrer at speed range 300-500 rpm was maintained time of 8 to 10 minutes. By the mean time the mold was preheated and chalk powder was applied in mould to avoid shrinkage of casting materials. The sixteen different samples were casted.

4.2 Heat treatment

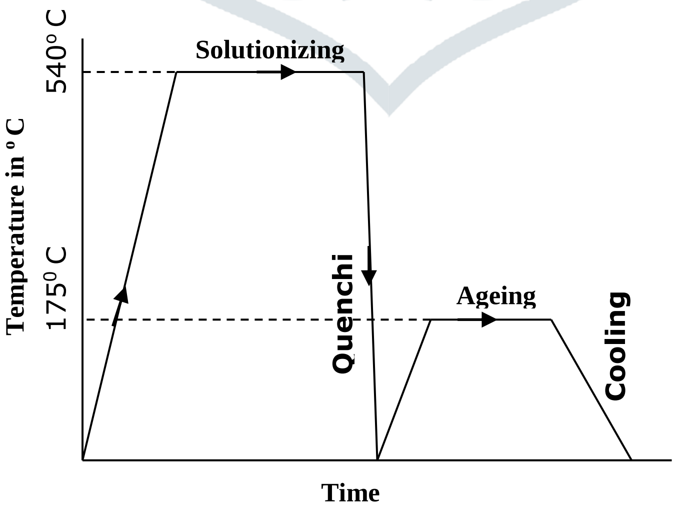


Figure: 4.1 Heat treatment process

One set of casted specimens were subjected to T6 heat treatment conditions. The heat treatment cycle is shown in the Fig 4.1.

- Solution heat treatment for 4 hrs at a temperature of 540^{0}C.
- Quenching in room air.
- Ageing for duration of 2 hours at 175^{0}C.

4.3 Wear test.

The aim of the experiment is to achieve the minimum wear rate and coefficient of friction. Dry sliding wear tests for different number of specimens was conducted by using a pin-on-disc machine (Model: Wear & Friction Monitor TR-201C) supplied by DUCOM. The pin was held against the counter face of a rotating disc EN32 steel disc (hardness of 65HRC) with wear track diameter 50 mm according to ASTMG99.

In the present experiment the parameters such as track diameter and time are kept constant throughout for all the experiments. Specimens of size 6 mm diameter and 30mm length were cut from the cast samples and machined. The samples and wear track were cleaned with acetone and also polished using emery sheets to obtain fresh surface contact between the two. The specimens were weighed before and after the experiment using a precision weighing balance up to the accuracy of 0.001gm to predict the mass loss.

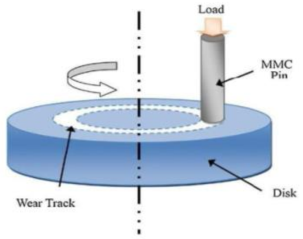


Fig 4.2 Schematic drawing of pin-on-disk wears test system.

5 Results and Discussion:

5.1 Wear Test Result for as cast specimens:

Figures 5.1.1 to 5.1.9 shows effect of Boron Carbide and Short Basalt Fiber Reinforced on wear behavior of AA2014 Based Hybrid composites at as cast condition.

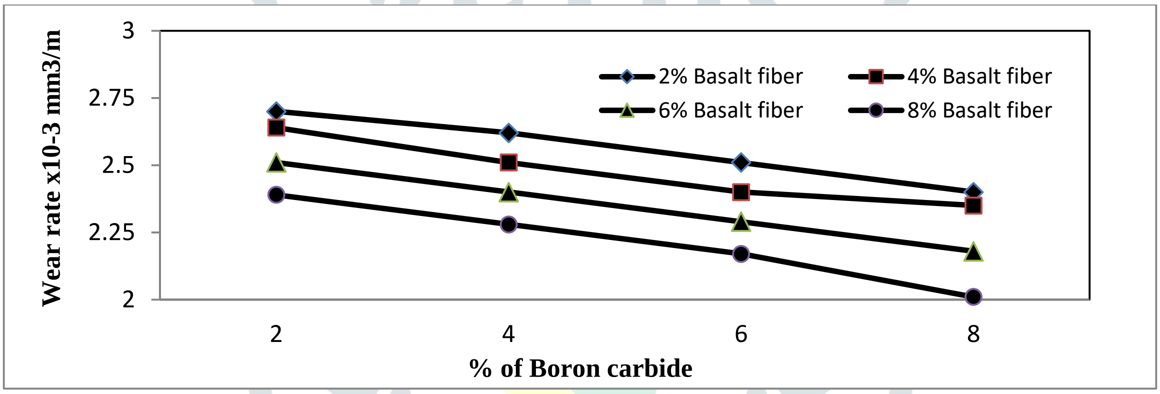


Fig. 5.1.1 The effect of Boron carbide and short basalt fibers on wear rate of the hybrid composites at as cast condition at load of 20N and speed of 200 rpm

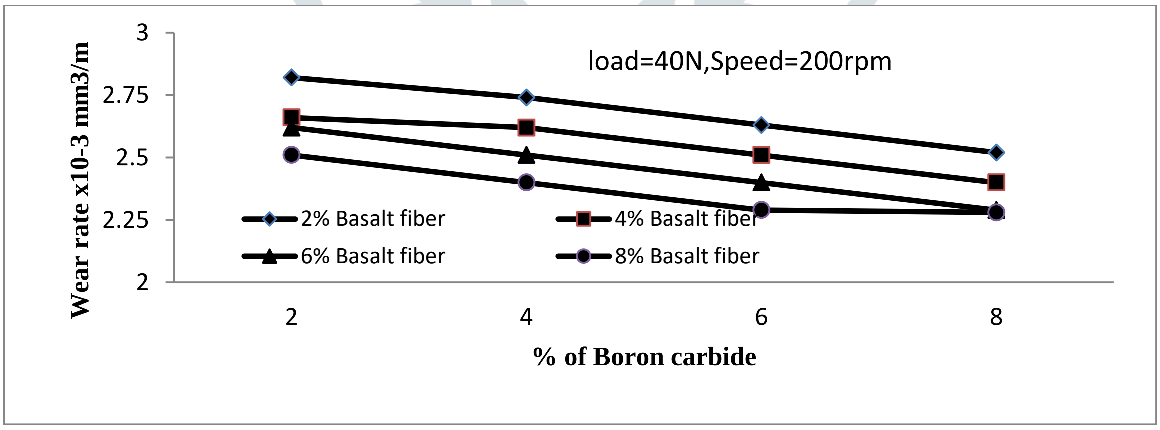


Fig. 5.1.2 The effect of Boron carbide and short basalt fibers on the specific wear rate of the hybrid composites at as cast condition at load of 40N and speed of 200 rpm

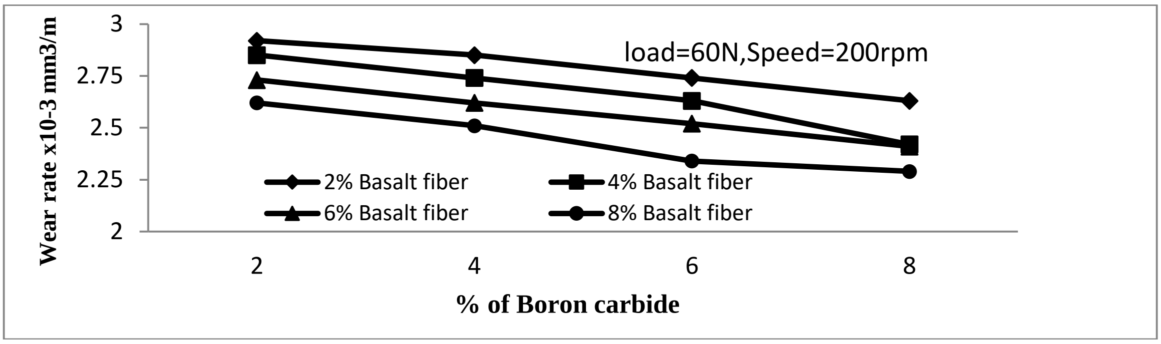


Fig. 5.1.3 The effect of Boron carbide and short basalt fibers on the specific wear rate of the hybrid composites at as cast condition at load of 60N and speed of 200 rpm

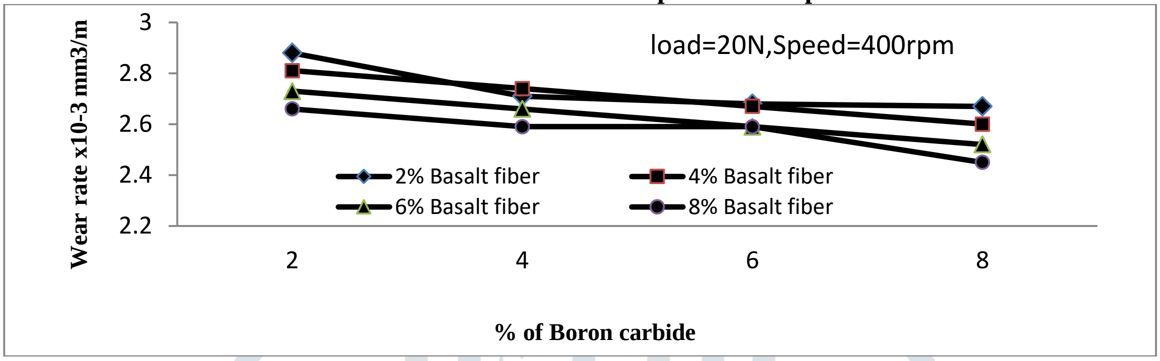


Fig. 5.1.4 The effect of Boron carbide and short basalt fibers on the specific wear rate of the hybrid composites at as cast condition at load of 20N and speed of 400 rpm

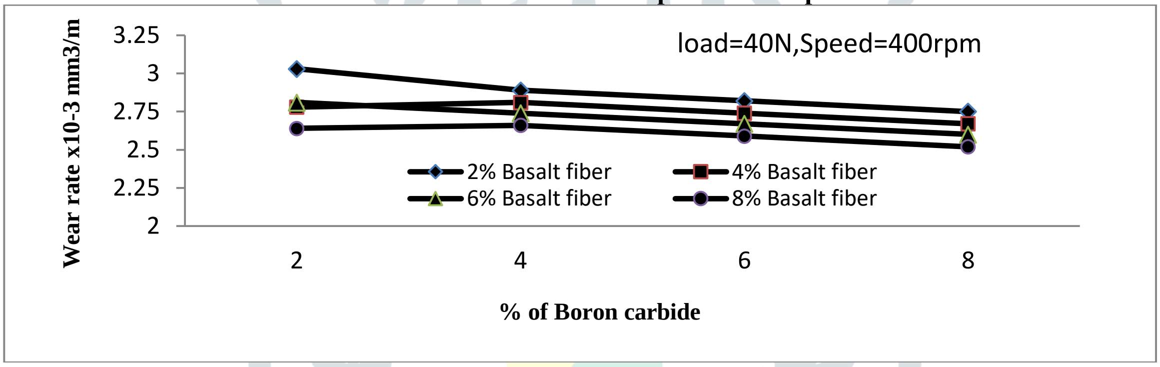


Fig. 5.1.5 The effect of Boron carbide and short basalt fibers on the specific wear rate of the hybrid composites at as cast condition at load of 40N and speed of 400 rpm

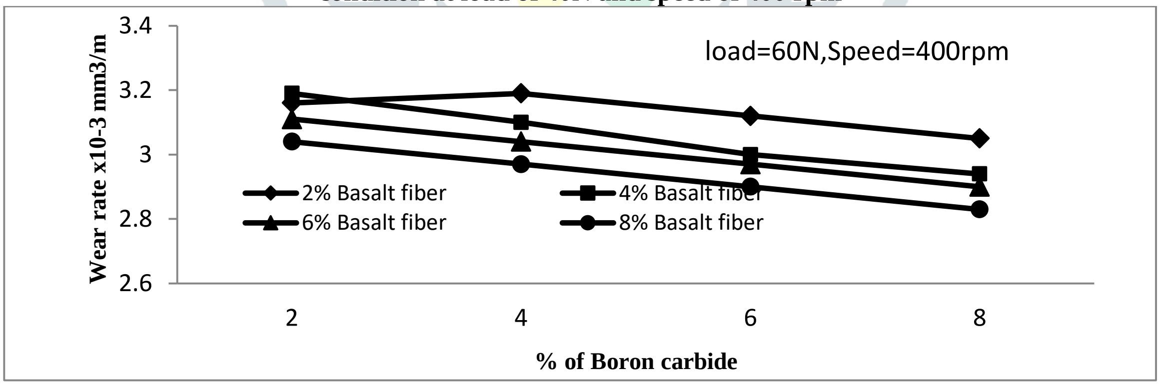


Fig. 5.1.6 The effect of Boron carbide and short basalt fibers on the specific wear rate of the hybrid composites at as cast condition at load of 60N and speed of 400 rpm

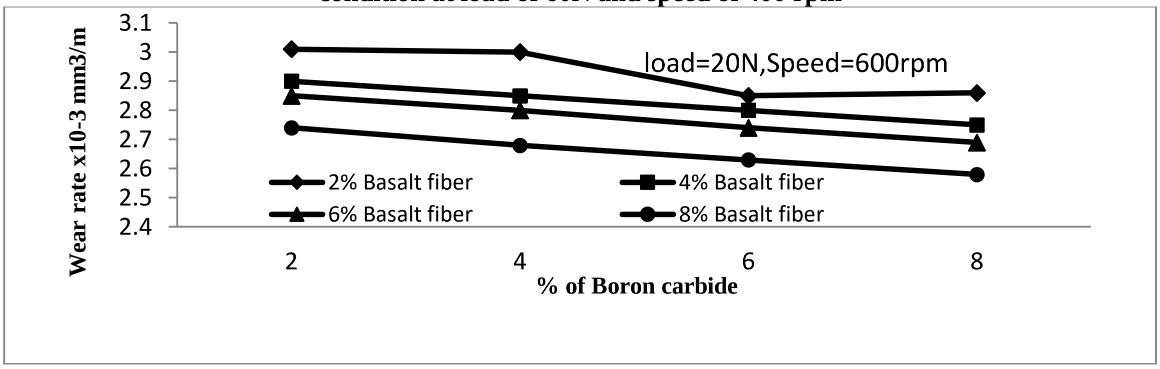


Fig. 5.1.7 The effect of Boron carbide and short basalt fibers on the specific wear rate of the hybrid composites at as cast condition at load of 20N and speed of 600 rpm

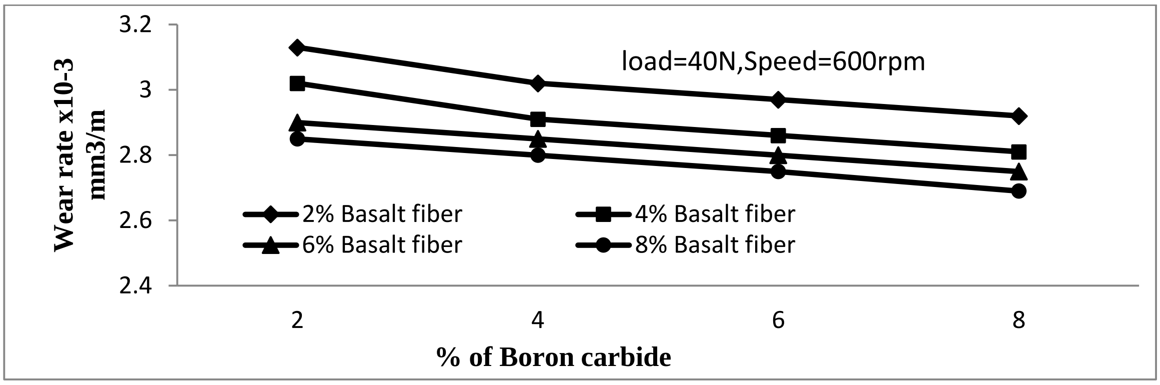


Fig. 5.1.8 The effect of Boron carbide and short basalt fibers on the specific wear rate of the hybrid composites at as cast condition at load of 40N and speed of 600 rpm

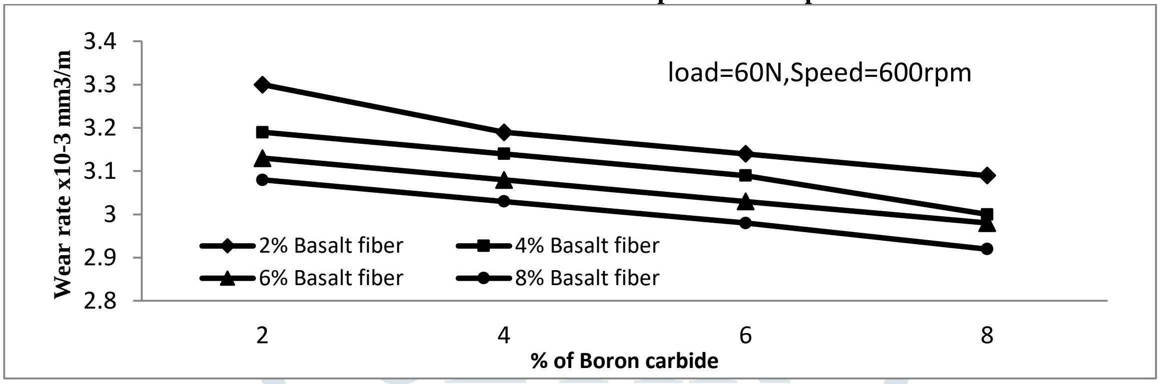


Fig. 5.1.9 The effect of Boron carbide and short basalt fibers on the specific wear rate of the hybrid composites at as cast condition at load of 60N and speed of 600 rpm

5.1.1 Effect of Boron carbide and short copper Basalt fiber on wear rate:

The Effect of Boron carbide and short copper Basalt fiber content on the wear characteristics of Al 2014 based hybrid composites for different speeds, loads and sliding distance is shown in Figs.5.1.1 to fig 5.1.9,

It is observed from the Figures that the wear rate of the composites decreases with the increase in reinforcement content. The reduction in wear rate is by as much as 10 to 15 % as the content of the Boron carbide (2 to 8%) and Short Basalt fibers (2 to 8%) varied and also observed that the effect of both boron carbide and short basalt fiber has been good wear resistance at all wear parameters.

5.1.2 Effect of normal load on wear rate

Figs.5.1.1 to fig 5.1.9 show a wear rate of Boron carbide/Basalt fiber reinforced Al2014 based Hybrid composites plotted against the applied loads of 20N, 40N and 60N. It is observed clearly from the graph that the wear rate of the composites increases with the increase in applied load. It is clearly marked from the graphs that there subjected to a higher load at which there is an abrupt increase in the wear rate of all hybrid composites. When the load applied is low, the wear rate is quite small, which increases with the increase in load applied. It can be considered that it is quite natural for the wear rate to increase with load.

5.1.3 Effect of sliding speed on wear rate

Figs.5.1.1 to fig 5.1.9 show a wear rate of Boron carbide/Basalt fiber reinforced Al2014 based Hybrid composites plotted against the Different speeds of 200rpm, 400rpm and 600rpm. It is observed clearly from the graph that the wear rate of the composites increases with the increase in speed. It is clearly marked from the graphs that there subjected to a higher speed at which there is an abrupt increase in the wear rate of all hybrid composites. When the speed is low, the wear rate is quite small, which increases with the increase in speed. It can be considered that it is quite natural for the wear rate to increase with speed.

5.2 Effect of heat treatment on Wear behavior:

Figures 5.2.1 to 5.2.9 shows effect of Boron Carbide and Short Basalt Fiber Reinforced on wear behavior of AA2014 Based Hybrid composites at heat treated condition.

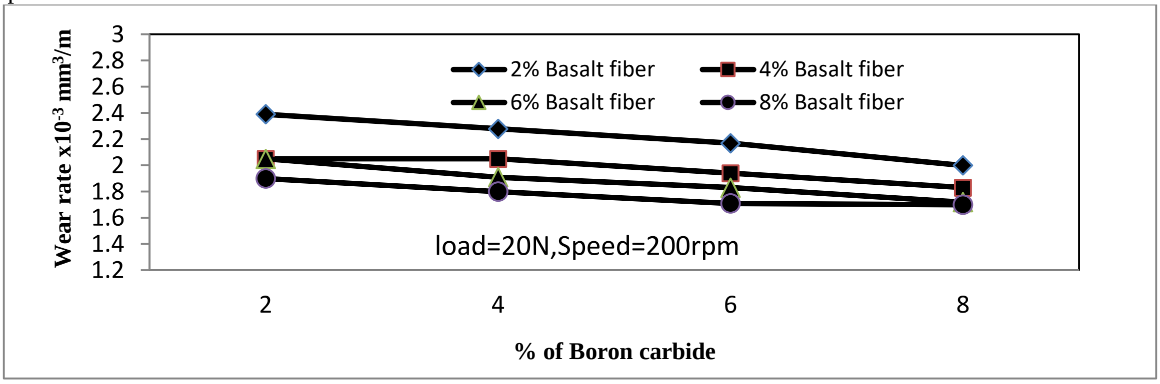


Fig. 5.2.1 The effect of Boron carbide and short basalt fibers on wear rate of the hybrid composites at heat treatment condition at load of 20N and speed of 200 rpm

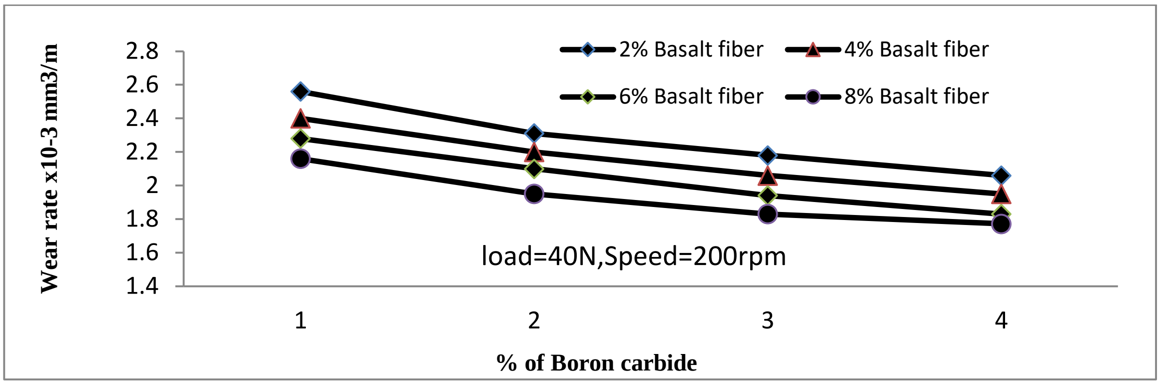


Fig. 5.2.2 The effect of Boron carbide and short basalt fibers on the specific wear rate of the hybrid composites at heat treatment condition at load of 40N and speed of 200 rpm

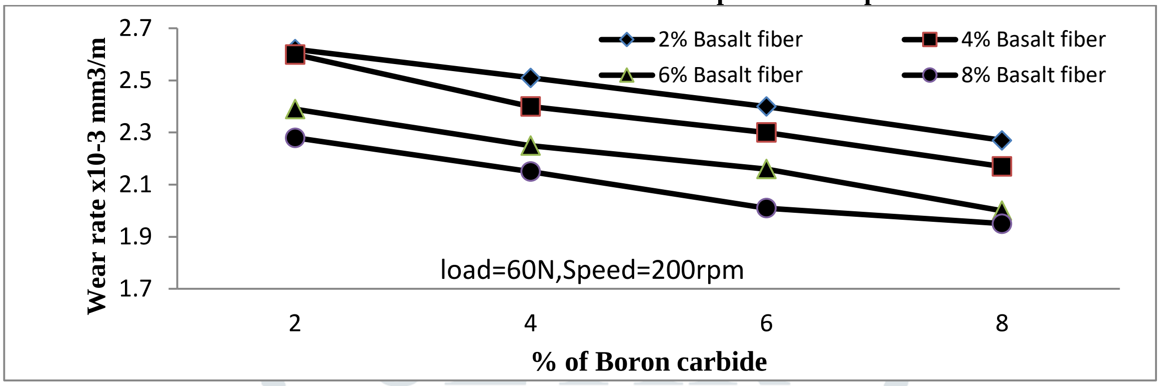


Fig. 5.2.3 The effect of Boron carbide and short basalt fibers on the specific wear rate of the hybrid composites at heat treatment condition at load of 60N and speed of 200 rpm

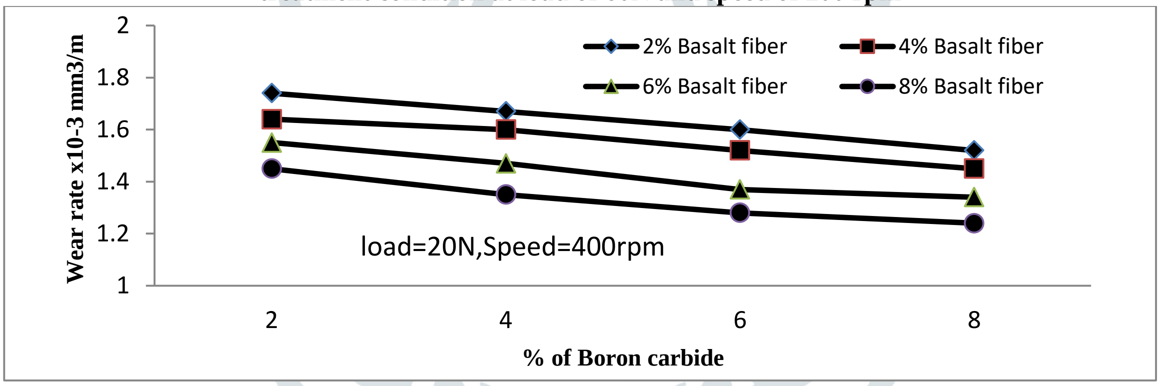


Fig. 5.2.4 The effect of Boron carbide and short basalt fibers on the specific wear rate of the hybrid composites at heat treatment condition at load of 20N and speed of 400 rpm

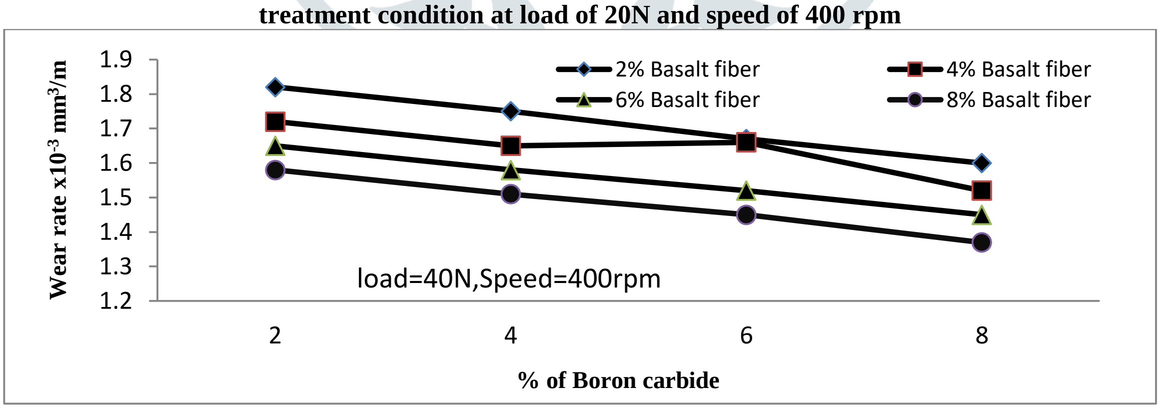


Fig. 5.2.5 The effect of Boron carbide and short basalt fibers on the specific wear rate of the hybrid composites at heat treatment condition at load of 40N and speed of 400 rpm

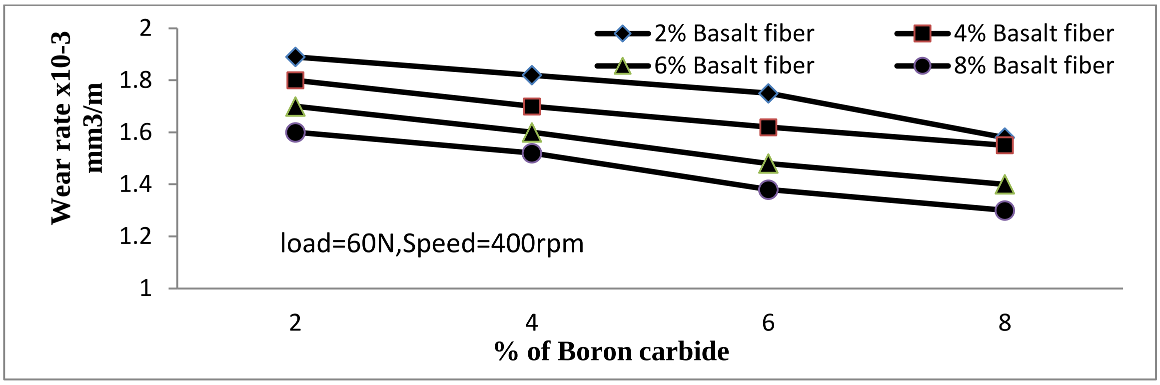


Fig. 5.2.6 The effect of Boron carbide and short basalt fibers on the specific wear rate of the hybrid composites at heat treatment condition at load of 60N and speed of 400 rpm

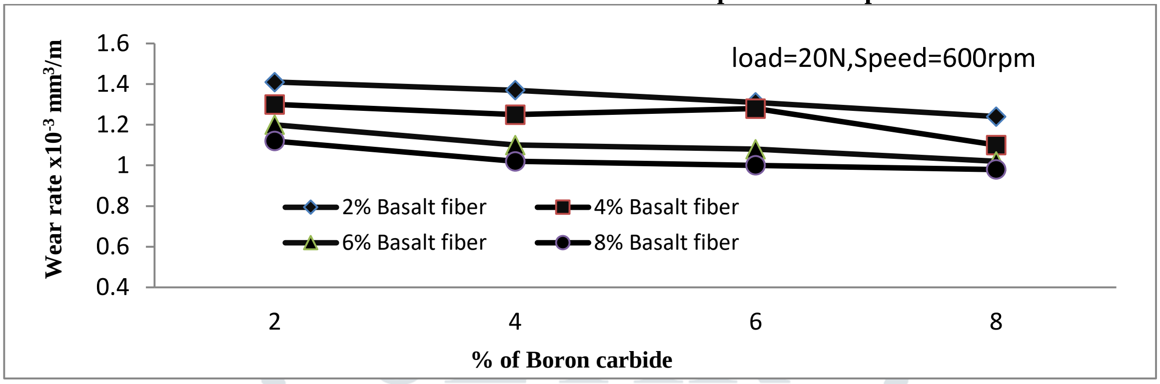


Fig. 5.2.7 The effect of Boron carbide and short basalt fibers on the specific wear rate of the hybrid composites at heat treatment condition at load of 20N and speed of 600 rpm

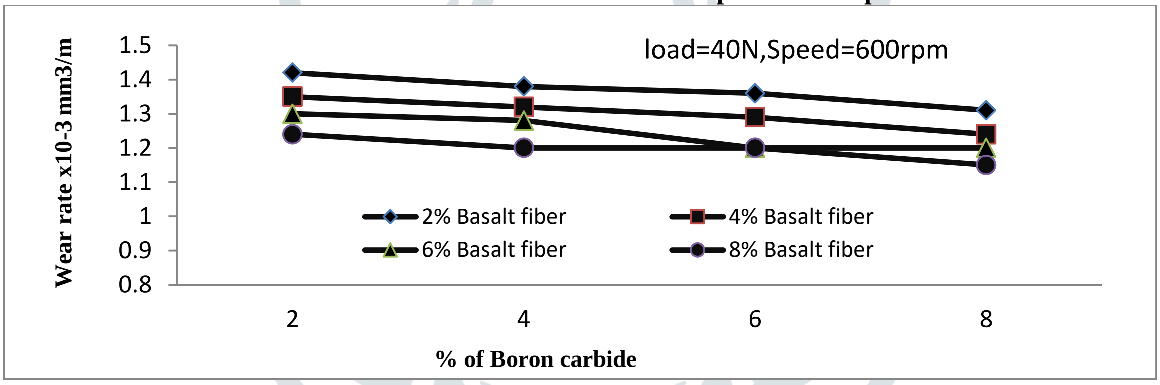


Fig. 5.2.8 The effect of Boron carbide and short basalt fibers on the specific wear rate of the hybrid composites at heat treatment condition at load of 40N and speed of 600 rpm

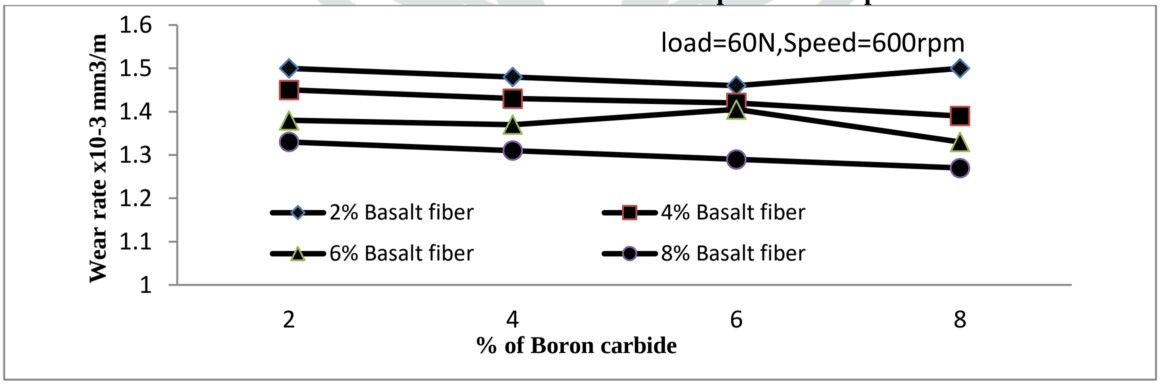


Fig. 5.2.9 The effect of Boron carbide and short basalt fibers on the specific wear rate of the hybrid composites at heat treatment condition at load of 60N and speed of 600 rpm

5.2.1 Effect of reinforcements with heat treatment:

The effect of reinforcements on wear resistance of heat treated Al2014 based hybrid composites for different speeds, loads and sliding distance is shown in figure 5.2.1 to fig 5.2.9

It is observed from figure 5.2.1 to fig 5.2.9 that there is progress in wear resistance of specimens subjected to heat treatment. Heat treatment has a reflective influence on the wear resistance of the Hybrid composites. For a solutionising temperature of 540^{0}C for duration of 4hr, quenching media room air and Ageing of 175^{0}C temperature for 2 hrs it's significantly enhances the wear resistance of the hybrid composites. The lowest material loss was observed at heat treated conditions as compared to ascast around 30 to 45% of wear rate improved at heat treated condition. It is observed from the Figures that the wear rate of the composites Decreases with the increase in reinforcement content.

5.2.2 Effect of normal load with heat treatment:

The effect of normal load on wear resistance of heat treated Al2014 based hybrid composites for different speeds and sliding distance is shown in figure 5.2.1 to fig 5.2.9.

It is observed from the figure wear rate of the hybrid composites increases with the increase in applied load. It is clearly marked from the graphs that there subjected to a higher load at which there is an abrupt increase in the wear rate of all hybrid composites. When the load applied is low, the wear rate is quite small. It can be considered that it is quite natural for the wear rate to increase with load and also observed that at heat treated conditions 30 to 45% of wear rate improved as compared to ascast specimens.

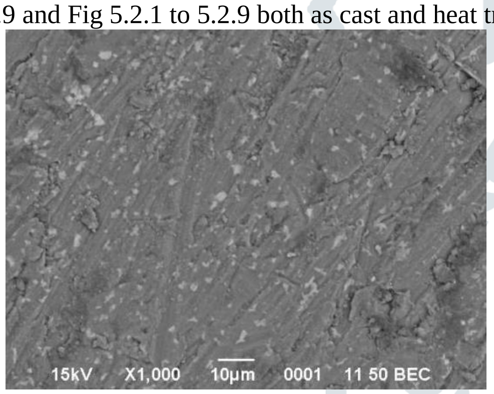
5.2.3 Effect of sliding speed with heat treatment:

The effect of sliding speed on wear resistance of heat treated AL2014 based hybrid composites for different load and sliding distance is shown in 5.2.1 to fig 5.2.9.

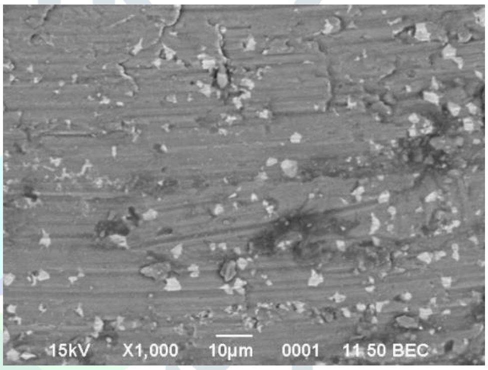
It is observed from the figure wear rate of the hybrid composites increases with the increase in sliding speed. It is clearly marked from the graphs that there subjected to a higher sliding speed at which there is an abrupt increase in the wear rate of all hybrid composites. When the sliding speed is low, the wear rate is quite small. It can be considered that it is quite natural for the wear rate to increase sliding speed and also observed that at heat treated conditions 30 to 45% of wear rate improved as compared to ascast specimens.

6. Scanning electron microscope analysis

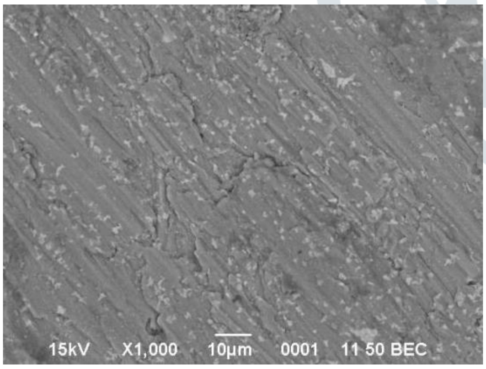
SEM analysis was done on the worn-out specimen for observing the wear behavior over the surface of the hybrid composite. Fig. 6 (a-d) shows the worn-out surface of the specimen at various load conditions. Material removal with few scratches was observed at low load (20 N) and grooves along the sliding direction were also found (Fig. 6(a) & (b)), which indicates minimum wear rate. With increase in applied load from 20 N to 60 N (Fig. 7(c) & (d)), more scratch and more grooves with delamination were observed on the surface this indicating the transition of normal wear to severe wear resulting in heavy metal removal rate. The reason behind this wear behavior was the plastic deformation between the rotating disc and the composite specimen at high load, resulting in high wear rate. This implies the drastic increase of wear rate from 40 N to 60 N in the graph shown in Fig 5.1.1 to 5.1.9 and Fig 5.2.1 to 5.2.9 both as cast and heat treated condition.



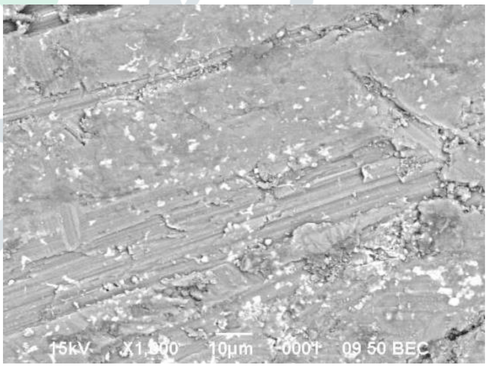
(a)



(b)



(b)



(d)

Fig 6.1. SEM analysis of worn-out specimens at different conditions (a) & (b) L=20N, n=600rpm, D=628m. (c) L=40N, n=600rpm, D=628m. (d) L=60N, n=600rpm, D=628m.

Conclusion:

The following conclusions can be drawn from the Experimental investigation of wear behavior of Al2014 reinforced with boron carbide and short basalt fiber based hybrid composites

- The stir-cast experimental set up could be successfully adopted in the preparation of Al 2014/B_4C/basalt fiber based hybrid composites.
- The wear rate is dominated by three different wear parameters like normal load, siding speed and sliding distance. With the increases in the weight percentage of reinforcements there is a decrease in the wear rate at all wear parameters'.

- At maximum of 8% boron carbide and 8% short basalt fiber shows lower wear rate of the composites and also observed the effect of both boron carbide and Short basalt fiber shows good wear rate at all wear parameters this may be due to presence of strong and hardened ceramic particles.

- Heat treatment T6 is a significant effect on the wear behavior of the hybrid composites. The heat treated specimens shows 30 to 45% better wear behaviour as compared to as cast specimens this may be due to morphology of the eutectic boron was spheroidal, and some light grey √ phases precipitated.

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