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Prediction of mechanical properties of hybrid aluminium composites

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ABSTRACT

The modern manufacturing industry needs highly characterized materials for a variety of applications, which leads the material researchers were focuses on hybridization in the aluminium metal matrix with various reinforcements. In this research investigates the mechanical properties of aluminium alloy Al 6061 with the reinforcement of silicon carbide and eggshell particles in various proportionalities. The stir-casting method is used to prepare the Al 6061 based hybrid aluminium composite material by varying the weight percentage of both silicon carbide and eggshell particles; the reinforcement material of eggshell increases the hardness of the material with least expensive. The Al 6061 based hybrid aluminium metal matrix test specimens were fabricated as per ASTM standards in the water jet machining process. The Al 6061 based hybrid aluminium metal matrix composite was characterized by various mechanical tests such as tensile load, tensile strength, percentage of elongation, yield load, yield strength, compressive strength, impact strength, impact energy and Rockwell hardness. In the tests reveals that performance of the pure aluminium alloy Al 6061 considerably lower value in impact tests. The 8 wt% of silicon carbide with 4 wt% eggshell particles reinforce hybrid aluminium metal matrix composite is performed very well in the tensile, compressive and hardness tests.
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1. Introduction

In recent years, usages of hybrid aluminium metal-matrix composites were considerably increased in many commercial fields due to its lesser weight, superior strength and reasonable cost [1]. Several researchers prepared different aluminium hybrid composites by adding different biodegradable and non-biodegradable reinforcement materials. The specific strength of the hybrid aluminium alloy AA2014 composites was found maximum than other composition when it was reinforced with 2.5 wt% silicon carbide and 7.5 wt% carbonized eggshell particles [2,3]. Tensile strength and hardness of the aluminium alloy Al 6061 metal matrix were found superior than other compositions when the metal matrix was reinforced with 5 wt% silicon carbide particles [4]. Improved tensile strength and hardness were observed in aluminium alloy 6061matrix-silicon carbide with reinforcement of aluminium oxide particles.

Some of the reinforcement materials addition into the metal matrix causes to lower toughness value of the composite [5,6]. Superior damping and mechanical properties were achieved in hybrid aluminium alloy composites when the metal matrix is reinforced with 7 wt% eggshell particles and 2.5 wt% magnesium-zinc particles [7]. The Higher strength, hardness, fatigue and wear resistance was observed in aluminium alloy composites when it was reinforced with silicon carbide and fly ash particles [8,9]. Mechanical behaviour of aluminum matrix-silicon particles reinforced composites were experimentally investigated [10]. Increased tensile strength, flexural strength and hardness were noticed in aluminium alloy AA 7075 composites when it was reinforced with 8 wt% silicon nitride particles [11]. The addition of 3 wt% waste eggshell particles and graphite particles into the aluminum alloy composites are enhanced the better compressive strength and harness [12]. Mechanical properties of the aluminium alloy AA2014 metal matrix composites were observed maximum when the metal matrix was reinforced with carbonized eggshell particles [13]. Wear behaviour of aluminium alloy AL 7075-T6 metal matrix-eggshell particles, silicon carbide particles and aluminium oxide

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particles reinforced hybrid composites were studied and the decreased wear rate was noticed in the hybrid composites than pure aluminium alloy composites [14].

Hybrid aluminium metal matrix was fabricated by adding the silicon carbide particles, carbonized eggshell particles, cow dung ash particles, snail shell ash particles, and boron carbide particles as reinforcement materials. Superior tensile properties and hardness were obtained due to the reinforcement materials [15]. Wear studies on aluminium alloy Al 6061 metal matrix-chicken eggshell particles reinforced were performed and the wear resistance of the chicken eggshell particles reinforced composites were considerably higher than that of pure aluminium alloy Al 6061 metal matrix composites [16]. Higher wear resistance and hardness were observed in aluminium alloy Al 6061 metal matrix composites when the mussel shell particles added into the metal matrix at 6 wt% as reinforcement material [17]. Hybrid aluminium metal matrix composites were prepared by using aluminium alloy AA 2024 as matrix, silicon nitride and magnesium oxide particles as reinforcement materials. Maximum tensile strength and Brinell hardness were noticed in 7.5 wt% of silicon nitride particles and 5 wt% of magnesium oxide particles [18]. In order to achieve and improve the mechanical properties of the aluminium alloy 6061 metal matrix composites, different researchers were added the various reinforcement materials with the aluminium alloy 6061 metal matrix composites and they have studied the effect of those reinforcements with the aluminium metal matrix. In this experimental work, initiation has been taken to evaluate the mechanical properties of the pure and silicon carbide particles, chicken eggshell particles reinforced hybrid aluminium metal matrix composites by varying the weight percentages of the reinforcement materials with aluminium alloy Al 6061 metal matrix.

2. Materials and methods

The conventional stir casting method was adopted to fabricate the pure and hybrid aluminium alloy composite materials. Initially, pure aluminium alloy Al 6061 pieces were taken as 20 mm long cylindrical pieces to minimize the melting time and maximize the effective melting of the aluminium alloy Al 6061. The waste chicken eggshells were obtained from different restaurants and the collected chicken eggshells were cleaned. Initially, the chicken eggshells were washed by pure water then it was washed by distilling water in order to remove the unwanted contamination in it, the well-washed waste chicken eggshell particles were then allowed for the drying process under atmospheric temperature for 48 h to eliminate the moisture content in it, shown in the Fig. 1. The chicken eggshells powders were obtained from the well-dried chicken eggshells by means of fine grinding process with the help of a mixer as shown the Fig. 2. The silicon carbide was procured in the powder form as shown in the Fig. 3.

In the preparation of hybrid aluminium composite; the appropriate weight percentage of aluminium alloy Al 6061 pieces were taken and feed in the induction furnace of the stir casting setup. The induction furnace temperature was set above the melting point of the aluminium alloy 6061, once the melting temperature reached the matrix materials were starts to melt. The increasing temperature of the induction furnace changes the entire solid aluminum alloy 6061 cylindrical pieces into the complete molten liquid stage. Once the liquid stage obtained in aluminium alloy 6061 material, the stirrer was turned on and it starts to stirring process. The induction furnace temperature was kept constant to the entire fabrication process. The appropriate weight percentage of reinforcement materials such as silicon carbide powders and chicken eggshell powders were also added into the molten matrix material.

The effective mixing of reinforcement materials with matrix material was achieved by utilizing continues stirring. After a one hour stirring process, the complete mixture of reinforcement materials with aluminium alloy 6061 metal matrix was made. The liquid aluminium alloy with reinforcement materials was poured in the rectangular die ($250 \times 250 \times 6$ mm) under the non-oxidation environment. Required test specimens were taken away from the pure and hybrid aluminium alloy rectangular plates by using a water jet cutting process with accurate dimensions as per the ASTM standards. ASTM E8-04, ASTM B209-14, ASTM E −09, ASTM E23-18 and ASTM B724 standards were adopted to make the test specimens and perform the different mechanical tests such as tensile, flexural, compressive, impact and hardness test respectively. The different compositions details of the Pure Aluminium Composite Samples (PACS) and Hybrid Aluminium Composite Samples (HACS) in weight percentages were given in table.1.

The pure aluminium alloy sample was named as PACS, which is not containing any additional reinforcement of silicon carbide and eggshell powder particles. The Al 6061 aluminium alloy matrix which is containing 2 wt% of silicon carbide particles and 1 wt% of waste chicken eggshell particles were named as HACS-1. The addition of 4 wt% of silicon carbide particles and 2 wt% of waste chicken eggshell particles with aluminium alloy matrix was termed as HACS-2. Aluminium metal matrix with 6 wt% of silicon carbide particles and 3 wt% of waste chicken eggshell particles were named as HACS-3. Inclusion of 8 wt% of silicon carbide particles

Fig. 1. Chicken Eggshells.

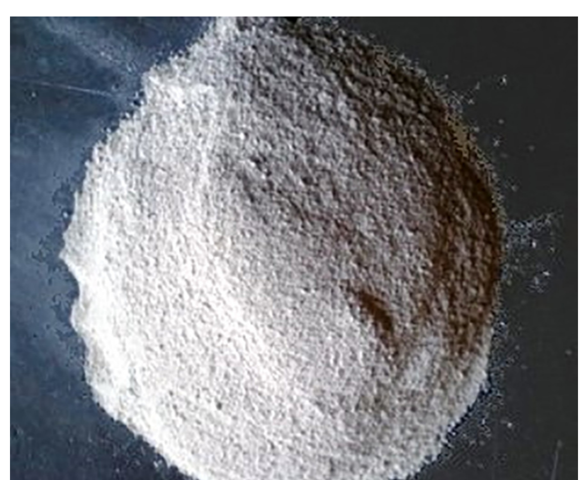

Fig. 2. Chicken eggshells powder.

Fig. 3. SiC powder.

Table 1
Composition details of Pure Aluminium Composite Samples (PACS) and Hybrid Aluminium Composite Samples (HACS) in weight percentage.

Composites	Aluminium Alloy 6061	Silicon CarbideParticles (SiC)	Chicken Egg Shell Particles
PACS	100	–	–
HACS-1	97	2	1
HACS-2	94	4	2
HACS-3	91	6	3
HACS-4	88	8	4

and 4 wt% of waste chicken eggshell particles was specified as HACS-4 respectively.

3. Results and discussions

The experimental studies were carried out on the pure Al 6061 aluminium alloy matrix and Al 6061 based hybrid aluminium composites. The mechanical behaviour of the pure Al 6061 aluminium alloy matrix with the various volumetric percentage of the reinforcement materials was studied; all the tests were done as per the ASTM standards. The various test results are presented and illustrated from Figs. 4 to 9 respectively.

The amount of tensile load revealed by the composite specimens during the tensile test was depicted in Fig. 4, from this figure it was found that the tensile load absorbed by the pure and hybrid aluminium composite specimens such as PACS, HACS-1, HACS-2, HACS-3 and HACS-4 were in the range of 18.96, 23.70, 29.63, 37.03 and 46.29 kN respectively. Minimum and the maximum tensile load of 18.96 and 46.29 kN was found in PACS and HACS-4 correspondingly. The tensile strength of the pure and hybrid aluminium composite specimens was illustrated in Fig. 5. The amount of tensile strength exposed by the pure and hybrid aluminium composite specimens such as PACS, HACS-1, HACS-2, HACS-3 and HACS-4 were found in the range of 56.78, 70.98, 88.72, 110.90 and 138.62 MPa correspondingly. Maximum and minimum tensile strength of 138.62 and 56.78 MPa was observed in HACS-4 and PACS respectively.

The tensile elongation percentage of the pure and Al 6061 based hybrid aluminium composite specimens was shown in the Fig. 6 The elongation percentages of all composites specimens were found in the range of 2.58, 3.23, 4.03, 5.04 and 6.30 during the tensile test. The HACS-4 and PACS observed maximum and minimum elongation percentages of 6.30 and 2.58 respectively.

The effects of silicon carbide particles and eggshell particles addition into the aluminium matrix on the yield load of the all-composite specimens were depicted in Fig. 7. The yield load of the pure and hybrid aluminium composite specimens such as PACS, HACS-1, HACS-2, HACS-3 and HACS-4 was found in the range of 11.45, 14.31, 17.89, 22.36 and 27.95 kN accordingly. Maximum and minimum load of 27.95 and 11.45 kN were found in PACS and HACS-4 respectively. The strength exhibited by the composite specimen under the yield loading conditions was illustrated in Fig. 8. Yield strength of the pure and hybrid aluminium alloy composites was found in the range of 38.94, 48.68, 60.84, 76.05 and 95.07 MPa for hybrid aluminium composite specimens such as PACS, HACS-1, HACS-2, HACS-3 and HACS-4 respectively. Maximum and minimum and yield strength of 95.07 and 38.94 MPa was found in HACS-4 and PACS respectively.

Strength revealed by the pure and hybrid aluminium composite specimens (PACS, HACS-1, HACS-2, HACS-3, and HACS-4) under the compression load was shown in Fig. 9, from this graphical representation, the compressive strength of the pure and hybrid

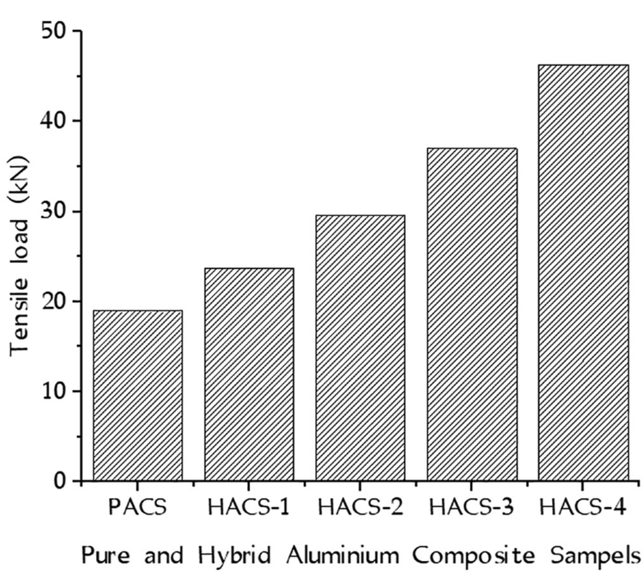

Fig. 4. Comparison of the tensile load of the composites.

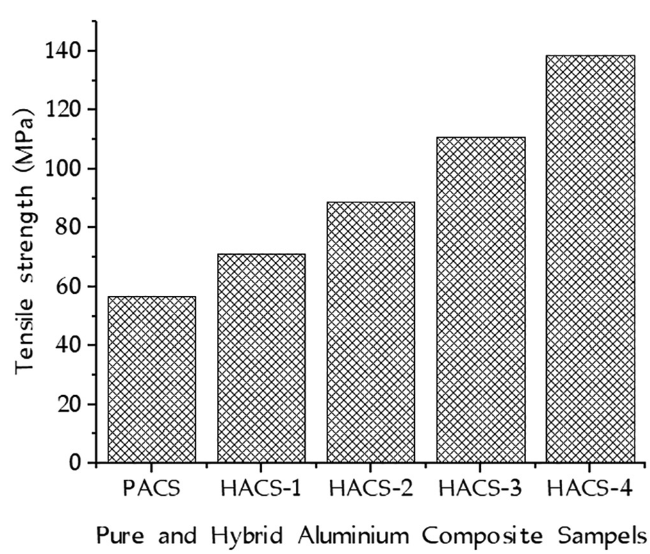

Fig. 5. Comparison of the tensile strength of the composites.

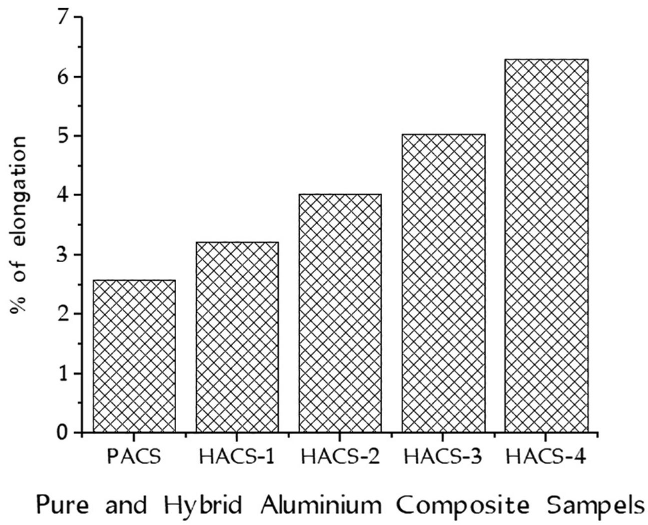

Fig. 6. Comparison of percentage of elongation of the composites.

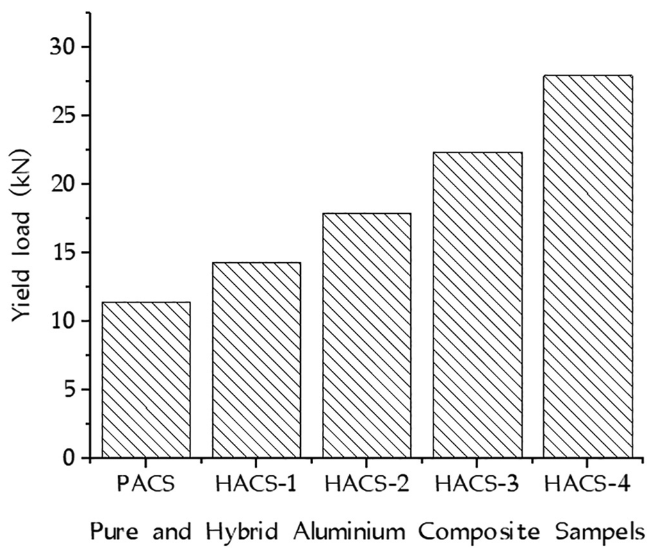

Fig. 7. Comparison of yield load of the composites.

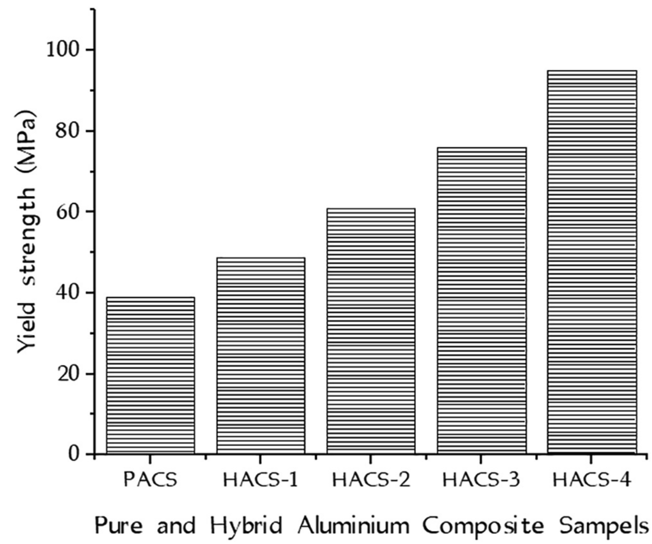

Fig. 8. Comparison of yield strength of the composites.

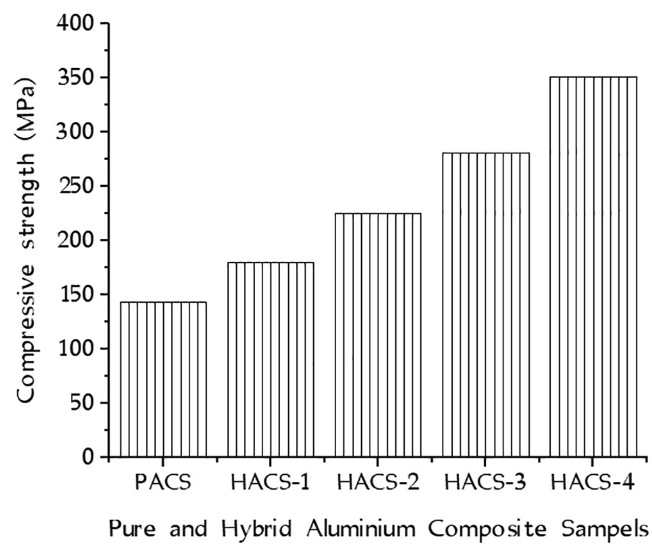

Fig. 9. Comparison of compressive strength of the composites.

aluminium composite specimens were found in the range of 143.86, 179.83, 224.78, 280.98 and 351.22 MPa respectively. The maximum compressive strength of 351.22 MPa was observed in the maximum percentage of eggshell particles with aluminium matrix and SiC particles. The lower compressive strength of 143.86 MPa was optained in pure aluminium alloy 6061 composite specimens respectively.

The amount of energy observed during the applied impact load on the composite specimens were shown in Fig. 10, from this figure it was noted that the amount of impact energy for the pure and hybrid aluminium composite specimens was decreased gradually for the lower silicon carbide particles and higher amount of eggshell particles. The amount of impact energy observed by the pure and hybrid aluminium composite specimens such as PACS, HACS-1, HACS-2, HACS-3 and HACS-4 during the Izod impact test was found in the range of 90, 72, 58, 46 and 37 Joules correspondingly. The maximum impact energy of 90 Joules was found at pure aluminium 6061 composite and the higher eggshell particles reinforced composite specimens observed the minimum impact energy of 37 Joules.

The strength of the pure and hybrid Al 6061 aluminium composite specimens that were exhibited that during the applied Izod impact loading conditions is depicted in Fig. 11. The impact strength values for the pure and hybrid aluminium composite specimens such as PACS, HACS-1, HACS-2, HACS-3, and HACS-4 were found in the range of 0.90, 0.72, 0.58, 0.46 and 0.37 J/mm^2. The maximum impact strength value of 0.90 J/mm^2 was exerted by the pure aluminium alloy 6061 and the minimum impact strength value of 0.37 J/mm^2; it was noticed that the maximum concentration of eggshell particles with the aluminium alloy matrix. The Rockwell hardness vales of the pure and hybrid aluminium composite specimens was depicted in Fig. 12. The Rockwell hardness values of the hybrid aluminium composite specimens such as PACS, HACS-1, HACS-2, HACS-3 and HACS-4 were found in the range of 59, 68, 78, 90, and 103 HRC respectively. Superior Rockwell hardness of the composite specimens 103 HRC was found in the maximum when the matrix is reinforced with a higher amount of SiC particles. The minimum Rockwell hardness of 59 HRC was found in pure Aluminium alloy 6061 composite specimen due to the absence of both SiC and eggshell reinforce-

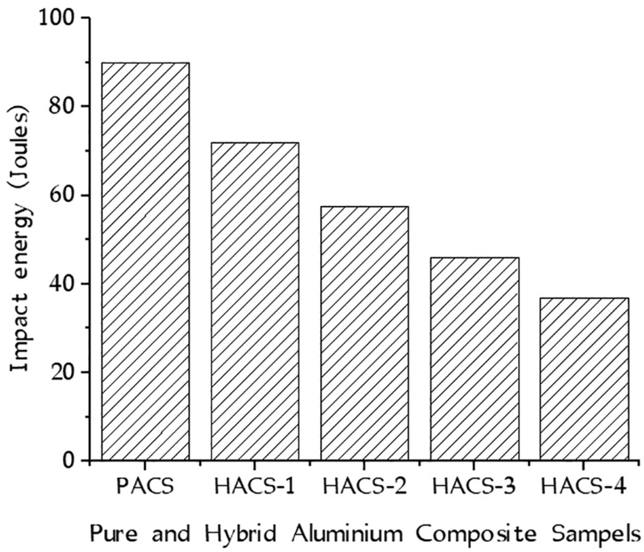

Fig. 10. Comparison of impact energy of the composites.

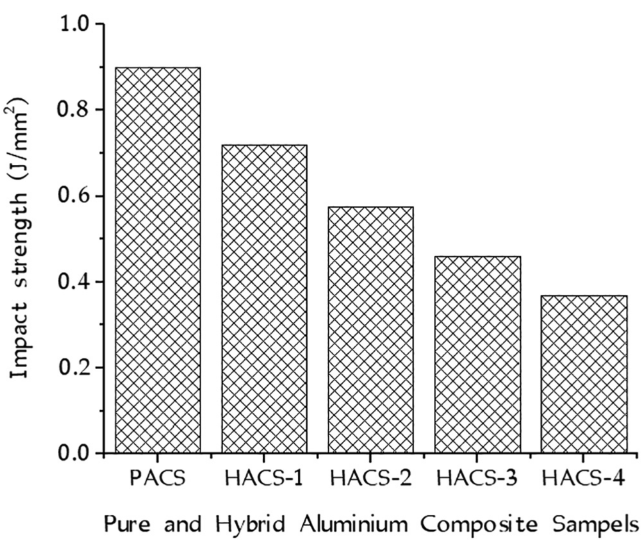

Fig. 11. Comparison of impact strength of the composites.

ment. The effective interfacial bonding between the matrix and reinforcement materials causes the enhanced mechanical properties of the composites.

4. Conclusions

The experimental investigations were carried out the Al 6061 based hybrid aluminium alloy, in this research work the Al 6061 composite was prepared with by varying the weight percentage of silicon carbide and eggshell particles. The five different compositions of materials were prepared and their mechanical properties were found by the various mechanical tests. The Al 6061 based hybrid composites' mechanical characteristics were improved due to the effective load shifting between the reinforcement materials. The addition of silicon carbide and eggshell particles into the Al 6061 matrix enhances the peak tensile load, tensile strength, percentage of elongation, yield load, yield strength, compressive strength, and hardness of the composites more than 50%, when

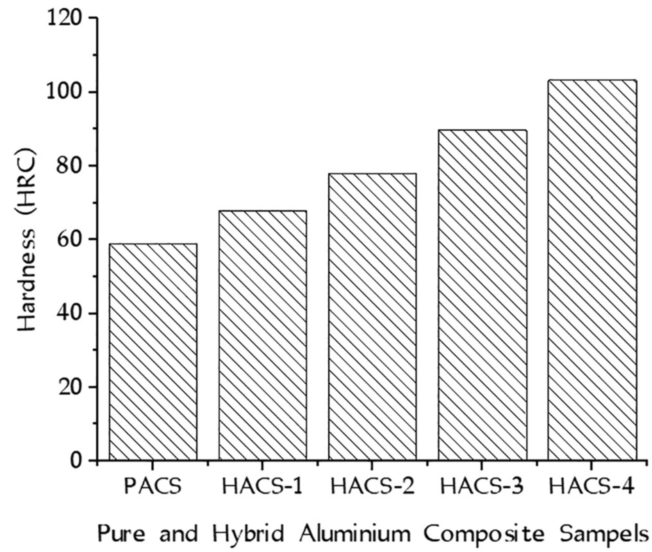

Fig. 12. Comparison of Rockwell hardness of the composites.

compared to the pure Al 6061 composites. The impact energy and impact strength of the hybrid aluminium composites were found minimum when compared with pure Al 6061 alloy due to the poor interfacial bonding between the reinforcement particles and matrix material during the application of impact load on the test specimens.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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