Research Article

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Optimization of mechanical wear resistance for recycled (Al-Mg-Si) reinforced SiC composite material using PM method

https://doi.org/10.1515/cls-2022-0023
Received Nov 02, 2021; accepted Feb 10, 2022

Abstract: Recently, the increasing demand for advanced materials around the world led to search on require and optimal materials characteristics. An alloy (Al-Mg-Si) named hindalium was used in this study which made from aluminum recycling (aluminums sandwich panel plates). In addition, powder technology was applied to investigate the effect of adding silicon carbide (SiC) particles on the composite properties that enter in fabricate of disc brake rotors. The main reason to use this technology is a single material cannot meet the demands of an extreme engineering setting that encourage towards necessitating the use of composites. Metal matrix composites are a type of material that has a lot of potential for components and structural applications that require a lot of unique modulus, strength, and durability as well as in the same time being light in weight. The composites materials of metal base with good properties are becoming now widely used in several industrial sectors due to their high mechanical properties and resistant to wear. Al-Mg-Si alloys are a common material category because of their inherent hardness, and corrosion resistance. The properties of hardness, wear rate, and microstructure are the physical and mechanical tests were performing in this study. It is indicated that the modeling with using a Genetic Algorithm is the best solution to choose the samples that have been prepared. According to the results, it was observed that the hardness increased by 14% at 15%SiC content and the wear rate decreased by 17% as comparing with the base alloy used in this study.

Keywords: Recycling, hindalium, optimization, genetic, composite, wear

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1 Introduction

It well known that the recycling means the re-process of melting metals to reuse it in the manufacturing process. The main benefit of using recycling metals is cost savings, less expensive and requires fewer resources to make a new product from recycled metal compared to their raw materials. According to the Al Association (2014), Al is still the most widely recycled commodity on the planet [1]. Aluminium and Aluminium alloys are utilized to produce structural parts for the industry of aerospace and also they considered very common metal to use in the building, packaging, and transportation industries. The power needed to manufacture 1 ton of Al from ores (Bauxite) is approximately 17000 kWh, whilst recycling it with the same amount requires approximately 750 kWh. As a result, the recycling process is needed to reach the requirements of cost and environment [2]. Aluminium sandwich panel plates are typically the most recycled materials due to their essential characteristics and flexibility as well as the fact that their alloys can be used in a variety of industries, including packaging, construction, furniture, electronics, and industrial installations [3]. Recycling is conserves resources and reduces raw material extraction and also combating climate change, rather than it burning or landfilling to be safer for the environment. Until now, most of councils have a lot of opportunity to improve collection systems and maximize the benefits of recycling by adopting the best practices [4]. The Al-metal is used in wide range of industrial applications due to the Low density and resistant to corrosion. Furthermore, it is also considered a good metal to use as

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conductor of electricity, which can be used in the transition of electrical applications and the manufacture of gears. The recycling a bulk of Al into other Al items or used in the manufacture of diffraction grating [5].

Aluminium sandwich panels are an environmentally friendly commodity that can be recycled and reused several times. As a result of that, recycling Al will save money, electricity, time, and valuable natural resources, which reflect in benefit on the local communities and economy [6]. It is reported that the main goal of the recycling project was to create a sustainable system loop that could turn all of the precious resources that would either be landfilled or burned as waste into useful items [7]. Aluminum's low strength can be strengthened by adding alloying elements such as Silicon, Zinc, Magnesium, and Copper. In contrast, the recycled Al from sandwich panel plates does not require these elements because it already contains alloying elements. However, aluminum's key flaw (wear resistance) persists [8]. The yield strength increased and the intermetallic hardening phase Mg_2Si are precipitates in the α-aluminum matrix, both can be formed from magnesium and silicon [9]. The addition of a ceramic reinforcing such as Al_2O_3 is to improve the wear resistance of pure Al by controlling the weight fraction, size, and distribution of constituents as well as by controlling the composite microstructure, mechanical properties, and wear mechanism. Previous study [9] reported that the ceramic reinforcing is favored because it does not react with the base metal at high temperatures and does not corrode. From the literature, adding high percentage of ceramic reinforcement (greater than 15%) as (particles, fibers, or whiskers) has a significant effect on the conductance of Al metal matrix in AMCs in every part of fabrication, heat treatment, and their widespread use in commercial applications. Besides, extrinsic and intrinsic effects are also present in these differences in composite [10].

It is stated that the vehicle pollution must be reduced because the automotive industry is under a lot of regulatory pressure. This has prompted the automotive industry to explore a variety of strategies for reducing vehicle mass, including the use of lightweight materials such as Al metal matrix composites (AMMC) [7]. One approach that has recently gained a lot of attention is replacing the conventional cast iron Disc Brake Rotor (DBR) with a substitute AMMC. The softening and overheating of the material result in low melting temperature 660°C which represent a significant problem associated with the use of Al alloy in disc brake rotors [8]. Nadeem and Kaushik [11] studied the addition 2.5% of Nano-SiC filler. They found that the enhancement is reach to 66%, while the tensile and flexural properties increased by 20%. The wear and coefficient of friction improved approximately by 10% [11]. Pawar and Abhay [12] studied the adding percentage mass ratio of silicon carbide in Aluminum metal as 2.5%, 5%, 7.5% and 10% and their effects on mechanical properties of the super gear. They obtained that an improving in hardness of prepared composite materials. In other side, they shown that the powder metallurgy technique for prepared is better that stir casting as more uniform distribution of SiC particles in the base of the composite [12]. Sandra *et al.* [13] measured the wear resistance with lubricated sliding condition of aluminum MMnCs reinforced with adding particles of SiC nanoparticles under the same conditions used in the test. They studied more factors influence on the wear rate with SiC addition such as sliding speed and normal load [13]. Suresh and Naresh [14] studied the wear mechanical property of Automobile Brake Pad System with dry sliding conditions used Al-Ti with different weight ratio of silicon carbide (SiC). They observed that the wear loss and COF are decreases gradually with increasing the wt.% of SiC particles in composite material [14]. The wear resistance effects by the hardness and the strength of developed composite. Also, the SiC has a significant effect on the mechanical properties of composite [15].

Prior work by Purkar *et al.* [16] investigated the wear resistance for Aluminum matrix composite with particles of Silicon carbide that used for brake pads. They noticed that the increase of SiC percentage in AL alloys leading to enhance the wear resistance and increase of friction coefficient. Pruthviraj *et al.* [17] investigated the strength, hardness and wear resistance of Zinc Aluminum based metal matrix composites that reinforced with silicon carbide particles (of size 50–100 μm). Sivananthan *et al.* [18] developed a composite with different volume percentage of reinforced particles of Sic and fly-ash with a base of Aluminum alloy 6061. They revealed that the composite with high reinforces particles have a high hardness and improved the impact and tensile strength. Al base alloy matrix reinforced by ceramic phase such as Alumina (Al_2O_3) and Silicon carbide (SiC) have been produced to advance prototype automotive components such as disc brake rotors and engine blocks for four-wheeled and two-wheeled vehicles [19]. The purpose of this study is to preparing lightweight Aluminium composite materials from recycle and reuses it in industrial applications (disk brake rotter straight and curved rotter vanes that used in race car professionals) airplane, marine and automobile structures. Furthermore, study the effect of adding SiC particles on mechanical wear resistance for Recycled (Al-Mg-Si) according to the PM method.

Table 1: Al alloy ingot chemical composition that prepared from Al sandwich panel plates

Elements	Al	Mg	Si	Mn	Fe	Cu	Zn
%	94.12	2.53	1.5	0.87	0.81	0.18	0.06

Table 2: Composition of samples prepared for this study

Samples	Mg	Si	Mn	Fe	Cu	Zn	Bal.
Al Alloy	2.53	1.5	0.87	0.81	0.18	0.06	94.12
5% SiC	2.53	1.5	0.87	0.81	0.18	0.06	90.12
10% SiC	2.53	1.5	0.87	0.81	0.18	0.06	90.12
15% SiC	2.53	1.5	0.87	0.81	0.18	0.06	90.12

2 Experimental work

2.1 Preparation of aluminium ingot

First of all, the Al sandwich panels were collected, washed, cut, and squeezed to reduce their volume and make the smelting process easier later. For the re-melting process, one kilogram of Al sandwich panel plates was weighed to find the ratio of Al after separation from slag. Smelted Al is being poured into ingots. 1Kg is melted at temperatures above 660°C in an electric melting furnace, to ensure that the majority of the components found in the chemical composition of Al sandwich panel plates melt. After removing the slag outside, the molten metal was poured into a steel mold. To assess the alloy's elements, a chemical composition examination was performed on an Al ingot.

2.2 Al-Mg-Si powder preparation

This stage entails cutting up Al alloy ingots into small parts (chips) utilizing a turnings machine with a 2.5 kW power, 1900 rpm spindle speed, and 0.5 mm/rev. feed rate in order to enhance the milling process later. After sieving with an electrical sieve shaker, Al alloy chips were milled in a planetary ball mill. To obtain aluminum alloy powders with the smallest particle size, the planetary ball mill was cycled at 6000 rev/min for several hours (more than 15hr).

2.3 Powders mixing

By using a four-point planetary ball mill, the silicon carbide (SiC) powders were combined with Al-Mg-Si alloy. Before test, weight percentages, alloyed and all primary powders were taken in a ball mill with acetone present. The SiC powders were mixed with Al alloy using a four-point planetary ball mill. Table 2 listed the four different metal matrix composites that were made. Initially, the weight percentages of all elemental powders were taken and alloyed in a ball mill with acetone present.

2.4 Powders compaction

An electrohydraulic compaction system with pressures of 300 and 400 Mpa was used to perform uniaxial compacting by double action die. Microstructure, hardness and wear tests were performed on cylindrical samples with a diameter and height by 18 mm and 6 mm, respectively. To take the samples outside the die, the dwell time and load were adjusted at 4 minutes and 1.5 tons, respectively. To make it easier for the samples to eject outside, the internal walls of the die were lubricated with graphite.

Figure 1: Electro hydraulic compaction device

2.5 Sintering

After compaction stage, in a vacuum sintering furnace (tube furnace with a high temperature), samples are sintered by heating with temperature of 773.15 K and a period of time for 2.5 hr. as well as allowing the samples to cool down within the furnace until they reach room temperature. After that, the samples will be able to be put into mechanical processing. The temperature of the vacuum sintering furnace used to make Al alloy composites increased at a rate of 10 degrees Celsius per minute.

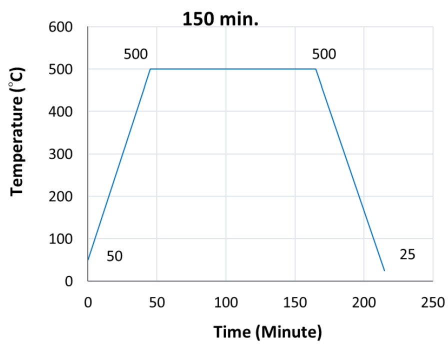

Figure 2: Sintering program

The existence of Mg in Al alloy which produced from sandwich panel may transforms from a solid state to a gaseous state (sublimate) at a temperature in range of 513.15 K, which causing emission steams and gases. Also, causing breaking the tube of vacuum furnace, and making the sintering process potentially dangerous. The vacuum tube furnace used for the sintering process is shown in Figure 3.

Figure 3: Vacuum sintering tube furnace

2.6 Microstructure test

During this test, samples were smoothed using smoothing paper of Al oxide with different smoothness (180, 220, 320, 400, 600, 800, 1000, 1200, 1500, 2000, and 2500) particles per-square-inch. The samples were polished with diamonds, and then washed with distilled water and alcohol. Finally, the samples are dried with an electrical drier after each phase. An appearance procedure (Etching) using a Keller reagent with a chemical composition of (95.5H_2O, 2.5HNO_3, 1.5HCl, and0.5HF), in which the samples are immersed in the solution for 10–20 seconds to avoid being burned, and then washed with alcohol and filtered water. An optical microscope was utilized examine to and analyses the structure of the samples.

2.7 Hardness test

Before putting all of the samples through hardness test, they were all grinding and polished with Al oxide smoothing paper of (180, 220, 360, 400, 600, 800, 1000, and 1500) particles per-square-inch. The test was performed on a Micro Vickers hardness, where a diamond pyramid of a square-base with a weight of 250g is falling down on the sample surfaces for 15 S. At least five values were recorded to measure the hardness from the surface of the samples.

2.8 Wear test

The pinned-on-disc technique is used to examine sliding wear and friction coefficient. The substance was omitted from the samples that were measured by weighing in this test (weight loss). The samples used in this work that needed to be examined were placed as a pin against a steel disk. The steel disk chemical composition was utilized for wear testing and martensitic with minor carbides and austenite; mean surface roughness is 0.113 µm; and Vickers hardness is 852.14 g/m^2. Furthermore, at room temperature 298.15 K the test was carried out, with loads of 15N, a steel disc rotational speed of 220 rpm, four time intervals of (5, 10, 15, and 20) minutes, and a sliding radius of 5 mm. The following equation was used to determine the wear rate [20]:

$$R.W = \Delta w / 2\pi r n t$$

Where, $R.W$ is the wear rate (amount of wear) g/m and Δw represent the weight loss (g) and the difference in sample weight before and after the test. The sample's radius in relation to the disc's center (5 mm) and rotational speed of the disc (200 rpm) are representing the r and n, respectively.

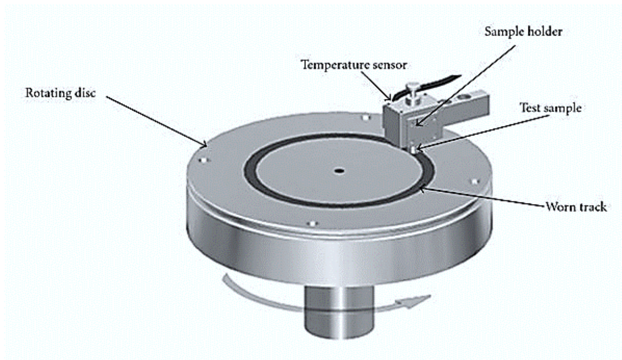

Figure 4: Pin on disk wear test

2.9 Measurement of friction coefficient

The friction coefficient of the composite made of pure Al and Al from sandwich panel was tested for a period of time and loads 20 minutes, 10 and 20 N, respectively. The results showed that the friction coefficient of samples is affected by the amount of SiC in them, but not by the compacting pressure used. Also, wear test parameters like time (sliding distance), rotational speed of the disk, and applied load [21]. With increasing SiC content and time, it is evident that the friction coefficient decreases. Figure 5 shows the relationship between friction coefficient and time for different weight fractions of SiC.

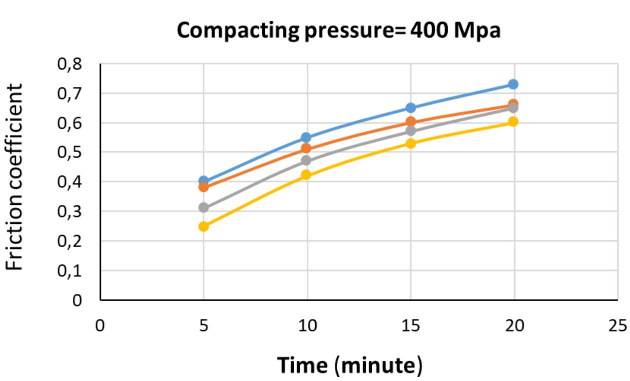

Figure 5: The effect of SiC percentage on the composite's friction coefficient over time

3 Optimization

3.1 Representation of solution

Genetic Algorithm (GA) is evolutionary calculation models instituted by Charles Darwin's theory of natural development based on the idea of the survival of the fittest. The linear and nonlinear functions are solved utilizing GAs by developing areas through selection, crossover and mutation operators applied to each chromosome in the population. GA uses many individuals; each of these individuals includes a chromosome representing a point in a search space of a given matter.

The GA chromosomes are a collection of actual values that indicate the properties values of composite produced in this work, which can be get by laboratory tests using language of Visual Basic (V.B). The gene that is equal to the length of a chromosome (N), whilst the gene length is complex. Hardness properties of the first gene are three genes long; the surface roughness properties of the second gene are three genes long; the wear rate properties of the third gene are twelve genes long; and the friction coefficient properties of the fourth gene are twelve genes long. Both of these genes are at various compacting pressures.

3.2 Implementation

The procedures for the genetic algorithm optimization operators used in this work are depicted in flow chart that shown in Figure 6. Since of operator in GA is independent of the others, there is no need to use all of them in a GA. The matter and the representation system used can influence the operator's choice or design. The operators built for twice strings, for example, cannot be used directly on strings coded with real or integer numbers. GA modeling was used to determine the best composite function values. The determination of certain parameters associated with GAs is needed at the beginning. These criteria include a population size of 100 individuals, a crossover with probability of 60%, a mutation with probability of 8%, and the total generation of 100 individuals.

Step 1: Utilizing Excel program, load the data results of the composite, which include 36 samples and 30 features that reflect the samples mechanical properties, like surface roughness, hardness, wear rate, and friction coefficient are f_1-f_3, f_4-f_6, f_7-f_{18}, f_{19}-f_{30}.

Step 2: Generate a population at random from the origin by change the data results of the composite into values in the [0, 1] field.

Step 3: Choose the crossover forms 1X, 2X, or Multi X and run the algorithm to detect the best solution.

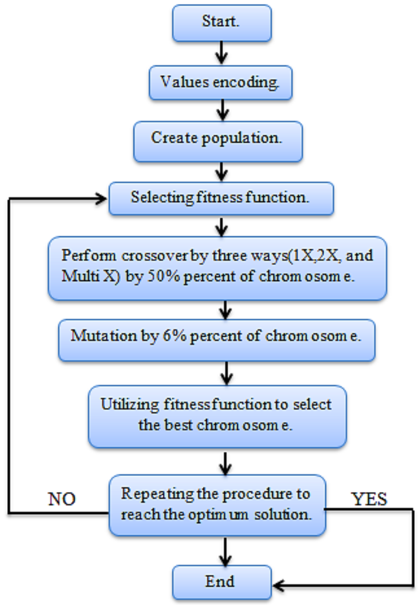

Figure 6: Flow chart of a simple genetic algorithm

4 Results and discussion

4.1 Optical microscopic analysis

The existence of Sic particles in the Al-Mg-Si alloy can be seen in the microstructure of Figure 7. It can be seen that the SiC improved the mechanical properties of the Al based, which can play as grains refiners as it considered as higher hardness particles than other compositions. According to the result, the increase of reinforced particles leads to refine the Al based grains with homogenous dispersion [22, 23]. This is obvious clearly in hardness and wear test results for different SiC particles percentage.

4.2 Hardness

Figure 8 shows that the values of hardness test of all samples vary as a function of SiC content and compacting pressure, and also obtained that adding SiC increases the hardness. The sample with 15 wt. percent SiC and a compacting pressure was found to have high hardness values 400 Mpa. These results are in agreement with previous study by Kumar *et al.* [24]. From Figure 8, the hardness of the prepared samples varies with SiC content and compacting pressure. The orange curve depicts hardness versus to SiC content at 300 Mpa compacting pressure, while the blue curve depicts hardness as a function of SiC content at 400 Mpa compacting pressure.

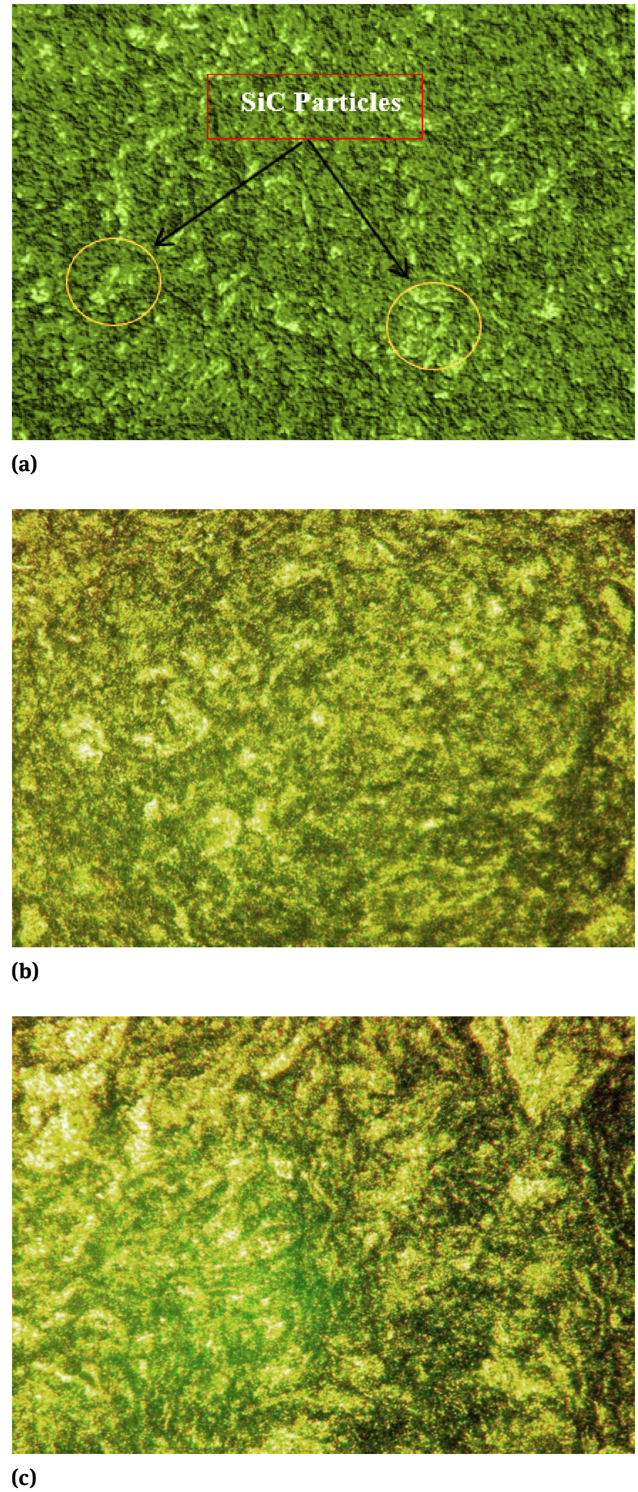

Figure 7: Microstructure of (a) Al alloy – 15% SiC), (b) Al alloy – 10% SiC) (c) Al alloy – 5% SiC), (600X magnification)

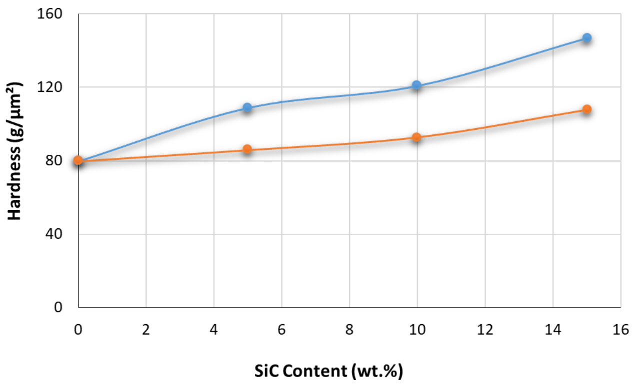

Figure 8: The values of composite hardness for various SiC percentage at (300 and 400) Mpa compacting pressure

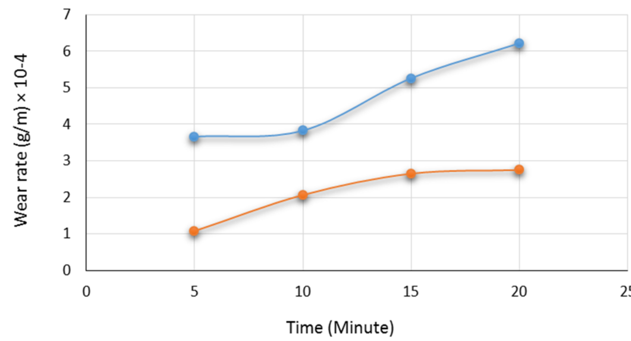

Figure 9: At 25°C, the effect of SiC percent on composite wear rate was investigated using a) a load of 10N and b) a rotational speed of 220 rpm

4.3 Wear Rate

Figure 9 shows the wear rate findings with time. The samples reinforced with SiC have a lower wear rate than the base, and the increasing compaction pressure leads to reduce the wear rate. The Al alloy samples have the highest wear rate, but as the SiC added the compaction pressure increased [25–27]. Furthermore, it was observed that the wear rate decreased gradually [28–30]. The influence of SiC percentage and compacting pressure on wear rate is shown in Figure 9. The orange curve depicts the alteration of wear rate with SiC percent at 400 Mpa compacting pressure, while the blue curve depicts the rate of wear alter with SiC percent at 300 Mpa compacting pressure.

4.4 Result of optimization

This study proposes a method to determine the optimal properties of composites by combining the hybrid approach, which characterized by numerical parameters and GA modeling, with the use of experimental data results. As a result, the data-base developed to classify composites is based on their properties. According to the optimization algorithm results, chromosome 33 is the best optimal composite for a 1X-crossover operator with the best properties. The chromosome 58 is the best optimal composite materials for a 2X-crossover operator with the best properties, chromosome with the best optimal composite for Multi X-crossover operator that provides the best properties is 15. In comparison to the experimental results, Table 3 shows the optimization algorithm's results reflected GA for the multi X-crossover operator.

Table 3: The optimization algorithm's results reflected GA for the multi X-crossover operator

Features	Experimental	Optimizations Algorithms	Features	Experimental	Optimizations Algorithms
f_1	149	151	f_{16}	$94.4*10^{-6}$	$95.1*10^{-6}$
f_2	136	134	f_{17}	$112.2*10^{-6}$	$112.7*10^{-6}$
f_3	151	152	f_{18}	$142.3*10^{-6}$	$142.9*10^{-6}$
f_4	$135*10^{-3}$	$140*10^{-3}$	f_{19}	$135*10^{-3}$	$177*10^{-3}$
f_5	$301*10^{-3}$	$297*10^{-3}$	f_{20}	$323*10^{-3}$	$327*10^{-3}$
f_6	$169*10^{-3}$	$178*10^{-3}$	f_{21}	$371*10^{-3}$	$377*10^{-3}$
f_7	$32*10^{-6}$	$33*10^{-6}$	f_{22}	$436*10^{-3}$	$415*10^{-3}$
f_8	$78.7*10^{-6}$	$79.1*10^{-6}$	f_{23}	$271*10^{-3}$	$283*10^{-3}$
f_9	$11.21*10^{-6}$	$112.1*10^{-6}$	f_{24}	$419*10^{-3}$	$431*10^{-3}$
f_{10}	$223.7*10^{-6}$	$224.1*10^{-6}$	f_{25}	$601*10^{-3}$	$578*10^{-3}$
f_{11}	$80.1*10^{-6}$	$82.4*10^{-6}$	f_{26}	$661*10^{-3}$	$652*10^{-3}$
f_{12}	$112.2*10^{-6}$	$111.9*10^{-6}$	f_{27}	$315*10^{-3}$	$299*10^{-3}$
f_{13}	$222.6*10^{-6}$	$223.4*10^{-6}$	f_{28}	$391*10^{-3}$	$382*10^{-3}$
f_{14}	$272.7*10^{-6}$	$272.4*10^{-6}$	f_{29}	$359*10^{-3}$	$347*10^{-3}$
f_{15}	$64.4*10^{-6}$	$64.1*10^{-6}$	f_{30}	$367*10^{-3}$	$339*10^{-3}$

5 Conclusions

According to the above review, the following findings are found from the current research:

1. It was indicated that the process of recycling used Al from sandwich panel plates that typically very fast, simple, and inexpensive.
2. Recycling is a method of preventing the accumulation of large amounts of waste by reprocessing and reusing it in the manufacture of new products.
3. It was found that the recycling of Al sandwich panel plates not only eliminates emissions and environmental issues caused by waste and landfill sites, but it also benefits the nation economically.
4. It can be concluded that powder technology was used to achieve a complete and homogeneous distribution of reinforcing phase within the matrix and as a casting substitute in some cases where small-scale manufacturing applications are needed.
5. Raising the compacting pressure and adding a reinforcing step SiC improved the hardness and wear rate.
6. In contrast to silicon, SiC enhance mechanical properties of composites while using a lower weight fraction. Furthermore, it can be used as a reinforcement process within an Al matrix to make disk brake rotors and automotive pistons.
7. The optimization GA aids in the reduction of development time by minimizing the number of experiences required to arrive at the optimal sample with the smallest relative absolute mean errors of the predicted values compared to the values obtained by experiment.

Funding information: The authors state no funding involved.

Author contributions: All authors have accepted responsibility for the entire content of this manuscript and approved its submission.

Conflict of interest: The authors state no conflict of interest.

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