The Effect of Machining Parameters in ECDM on Hybrid Composite Materials: Review Article

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Hybrid composite materials have significant industrial use when the strength-to-weight ratio, high mechanical properties, balanced strength and stiffness, low cost, and ease of fabrication are required. Hybrid composites are frequently utilized when compensation of features of different types of fibers has to be achieved. the use of hybrid composite materials has seen various innovations for a large variety of applications. In current paper presents a review to study the types, mechanical properties, and applications of hybrid composite materials on the industrial, engineering, and medical levels. As well as the review paper includes machining the nonconductive hybrid polymer matrix composite by electrochemical discharge machining technique and finding the important factors that influence the final results. Moreover, this review article displays the parameters which are affected the mechanical properties of hybrid composites. In addition, types of hybrid composite materials are mentioned in this review paper. Furthermore, this article review has been discuss effect of composite material and parameters in Electrochemical Discharge Machining (ECDM) process on the mechanical properties, surface roughness, Material removal rate.

Keywords: fibers reinforcement, mechanical properties, wind turbines, automotive structure components, hybrid composites, dental fillings, ECDM.

1. Introduction

The hybrid composites have no less than two of distinct fiber kinds. It is feasible to construct composites with superior all-around sets of attributes by employing hybrids than composites containing only one type of fiber [1]. On the other word, a different class of hybrid composites was generated by combining fiber and particle fillers in a singular polymeric or metallic matrix [2]. Fibers can be represented as the basic structure of the hybrid composite material, which are resistant to stresses and mechanical loads, and provides strength and stiffness to the composite. While the main role of the matrix (continuous phase) is to contain the fibers, give the final external shape to the hybrid composite material, protect the fiber material from all external factors, transfer the stress load applied to the hybrid composite material to the reinforcing material. The popular approaches include both carbon and glass fibers in a polymeric matrix, while there are many other fiber components and matrix substances in use. Although they are costly, carbon fibers are rigid, somewhat stiff, and offer low-density reinforcement. Glass fibers are less costly than carbon fibers, however they are less rigid. The glass–carbon hybrid is tougher and harder, has a higher tensile strength, and have lower cost of production compared of completely-carbon or completely-glass reinforced polymer matrix. The final characteristics will change if the two distinct fibers are blended in several of methodologies. For instance, the fibers may all be aligned and tightly mixed together, or laminations made of layers with one fiber type per layer alternated between them may be created, as shown in figure1.

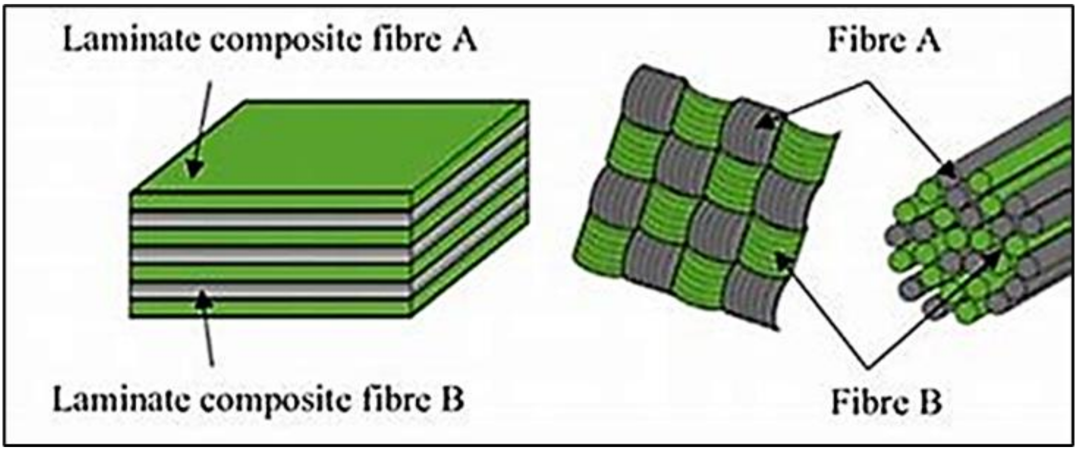


Figure 1: Two types of hybrid processing

The properties of almost all hybrids are anisotropic. When tension is applied to hybrid composites, fracture typically does not happen immediately (its expected failure), with the carbon fibers breaking first and the load subsequently shifting to the glass fibers, eventually causing them to fail and required the matrix phase to provide support for the applied load. Eventual composite failure is consistent with matrix phase failure. Major uses for hybrid composites are medical, wind turbine blends, and air transport structural components, automotive parts, electrical industry and marine manufacturing [1].

When the reinforcing materials are appropriately added to correct combinations of matrix, we will obtain exceptional properties different from two constituents. Strengthening of the connection at the matrix-fiber boundary is necessary to improve the mechanical behavior. provided that one of the constituents retain their identities in the composite, that is they do not melt and incorporated completely into each other, just a mechanical reaction [3].

Several factors effect on the mechanical properties of hybrid natural composites [4]. These factors include [5]:

- Diffusion and transmission of reinforcement in the proper matrix
- An interfacial bond between the fibers' surface and polymer matrix

- A vast surface area
- A large aspect ratio
- Reinforcement attributes
- The mechanical load effects
- Surface changes

Regarding cutting or milling non-conductive materials, ECDM (Electro-Chemical Discharge machining) is far superior to other machining processes since it efficiently produces high-quality surfaces. Fizeau and Focault were the first ones who detailed description the ECDM process in 1819 [6]. C.S. Taylor discovered electrical discharge at the electrode tip for the first time in 1925 [7]. The ECDM technique was established for the first time by Kurafuji and Suda in 1968 [8].

2. Electrochemical Discharge Machining (ECDM) of Hybrid Composites:

Electrically conductive and non-conductive materials can be machined using the hybrid non-conventional machining technique known as electrochemical discharge machining (ECDM) [9]. Due to their superior durability and strength, ceramic particulates (SiC) reinforced polymer matrix composites have become well known among composite materials. However, because of their embrittlement and the abrasiveness of the reinforcing particles, these kinds of substances are regarded as being difficult to process materials. Therefore, becomes required to achieve this goal by creating a machining technique that can be widely applied to the machining of these kinds of substances. As a result, several investigations using the response surface methodology have been conducted to enhance the machining parameters of electrochemical discharge drilling. Electrolytic concentration, voltage, and inter-electrode spacing, three process variables, were examined to determine how they affected the features of the final product. The most important variables for material removal rate and over cut, respectively, are found to be voltage and inter-electrode gap. Using Design-Expert software, the tests were designed according to the Box-Behnken method. Table 1 displays the range of variables used during the process. The outcome of the studies was the material removal rate as well as over cut was significantly affected by voltage. Material removal rate (MRR) directly proportional with the voltage, even though during electrochemical discharge drilling or machining processes of hybrid polymer matrix composites (PMCs), the highest MRR was noted in the range of 60-70 V.

Table1 levels and process variables.

Symbol parameter	Symbol parameter	Unit level	Low (-)	Intermediate (0)	High (+)
A	Electrolyte conc.	g/l	90	100	110
B	voltage	V	50	60	70
C	Inter-electrode gap	mm	100	120	140

The inter-electrode gap has been shown to be the most important factor affecting the cutting. By maintaining a parametric setting of a minimal inter-electrode spacing and an electrolytic concentration of 100 g/l, overcutting during machining can be reduced.

Voltage and inter-electrode spacing are revealed to be the most important factors which influence final quality features, according to an ANOVA table for MRR and over cut [10].

Electro Chemical Discharge Machining (ECDM) is a combined ECM and EDM process that makes it possible to simultaneously machine electrically conductive materials at a rate that is approximately 5 to 50 percent quicker in comparison to ECM & EDM, regardless of the typical characteristics of newer materials like chemical inertness and high strength high temperature resistance (HSHTR). The uniqueness of this method is that it can also be used for machining HSHTR materials that are electrically nonconductive and challenging to work with using traditional techniques [11]. Figure 2 illustrations the operating system for the ECDM process.

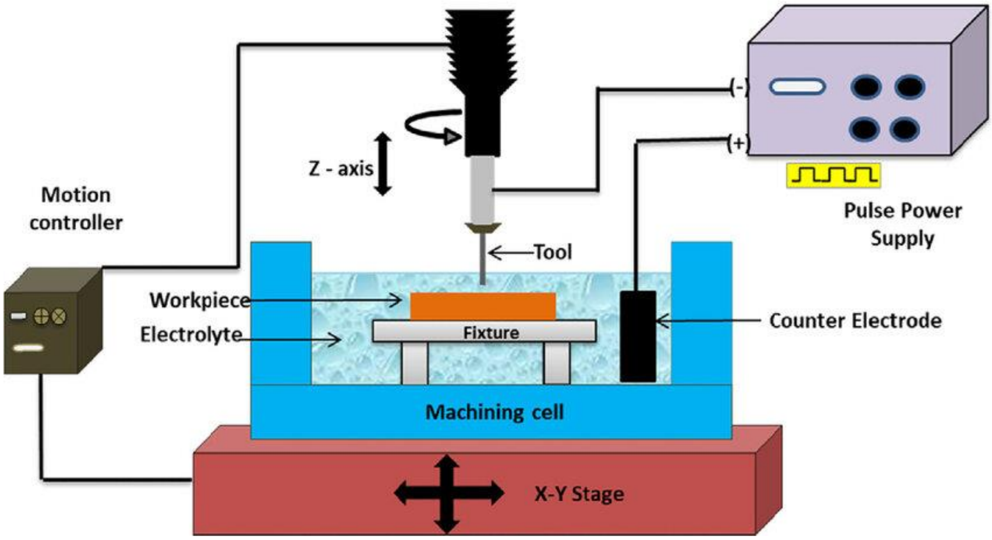


Figure 2: working principle of ECDM process [12]

Abbas f. Ibrahim and etal, Investigate the process of EDM applied to a hybrid composite material comprising aluminum (6061) reinforced with 5% silicon carbide (SiC) and 10% Boron Carbide (B4C) this research improving the understanding of EDM process on hybrid composite and can assist in optimizing the machining parameters for achieving desired surface quality and productivity in industrial applications. The experimental results showed an increasing in MRR while the effect of pulse-off time and electrode rotational speed on MRR is comparatively less significant, the harder reinforcement particles lead to increase tool wear which affected the MRR and surface roughness outcomes.[13]

Saad k. Shather and etal, investigate effecting using the composite electrode (70%copper-30% silver) instead of pure copper electrode on the MRR, surface roughness (SR) of the specimen and the tool wear rate (TWR). Experimental results are shown that the composite material, which is represented by the copper-silver electrode produced an improved MRR with a reduced TWR than the conventional copper electrode. Furthermore, Composite electrodes (Cu-Ag) work more effectively than copper electrodes at reducing surface roughness [14].

Abbas F. Ibrahim and etal, used composite material compound of aluminum alloy matrix reinforced with SiC particles prepared by stir casting. The research was aimed to find effect of input parameters expressed of EDM by pulse current, pulse on duration and pulse off duration on the MRR and SR by using composite material workpiece (6061 alloy and 10% SiC). The experimental results show that the pulse current has a greater impact on the SR and MRR compared the other two variables. The optimum reading for the surface roughness (Ra) was obtained (1.032 μm) at pulse current (10 A), pulse on duration (100 μsec) and pulse off (15 μsec). The process's productivity (MRR) achieved its peak at Pc (30 A), pulse on (200 s), and pulse off (6 s), with a best-case outcome of 69.49 10-3 g/min [15]. As did the previously mentioned researcher a studying about current, pulse on time and duty factor on the microstructure, The examination of the microstructure from trials 2 and 4 is shown in detail in Figures 3 and 4, where the machining parameters are current (10 A), pulse on time (50 sec), and duty factor (0.45%). While the machining parameters in Fig. 4 at current (30 A), pulse on time (200 sec), and duty factor (0.45%) showed the existence of a lot of molten metal on the surface together with deep holes and tiny cracks. When the Pulse on value is raised over time, more discharge energy flows out, producing greater heat. This causes the material particles on the workpiece's surface to melt and evaporate, leaving behind big, black holes. The remaining molten material forms debris and sphere-shaped pellets as it returns to the surface.[15]

Abbas F. Ibrahim, aimed to explore and optimize the machining parameters in the process of electrochemical machining ECM of aluminum metal matrix composites (AMMCs), the variable parameters included current density, feed rate, electrolyte concentration, and electrolyte type. The experimental results showed that the increased in electrolyte concentration led to higher MRR, lower current densities and appropriate electrolyte concentrations were found to improve the surface finish of AMMCs during ECM, the study emphasized the importance of balancing material removal rate with achieving the desired surface quality. The studied conducted the microstructural analysis to evaluate the integrity of the machined AMMCs, the results indicated the optimized machining parameters led to minimal microstructural damage and better preservation of material properties.[16]

When the carbon interacts with the molten metal, it naturally forms stronger bonds than the original element during the cooling process, and cracks emerge when the pressure on the surface is greater than the material's ultimate tensile strength.

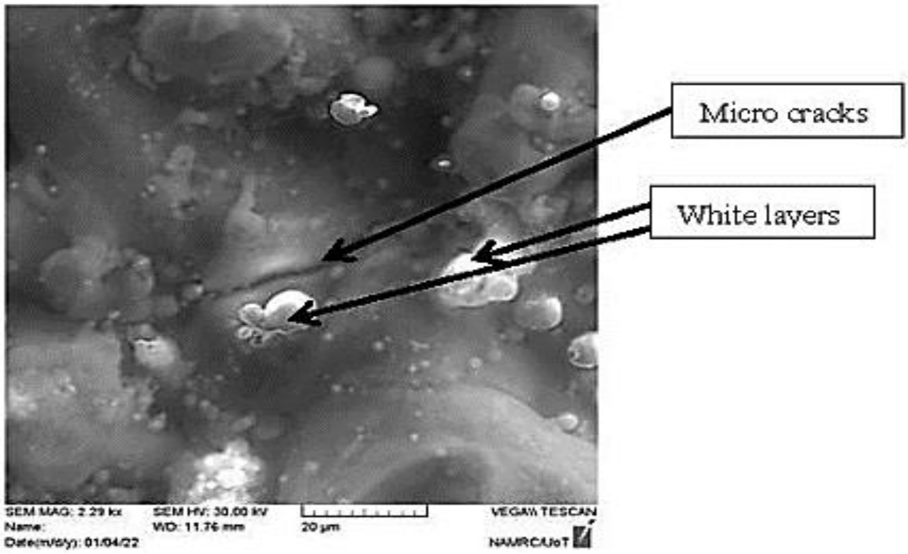


Figure 3: Microstructure of a low-energy-input machined surface.

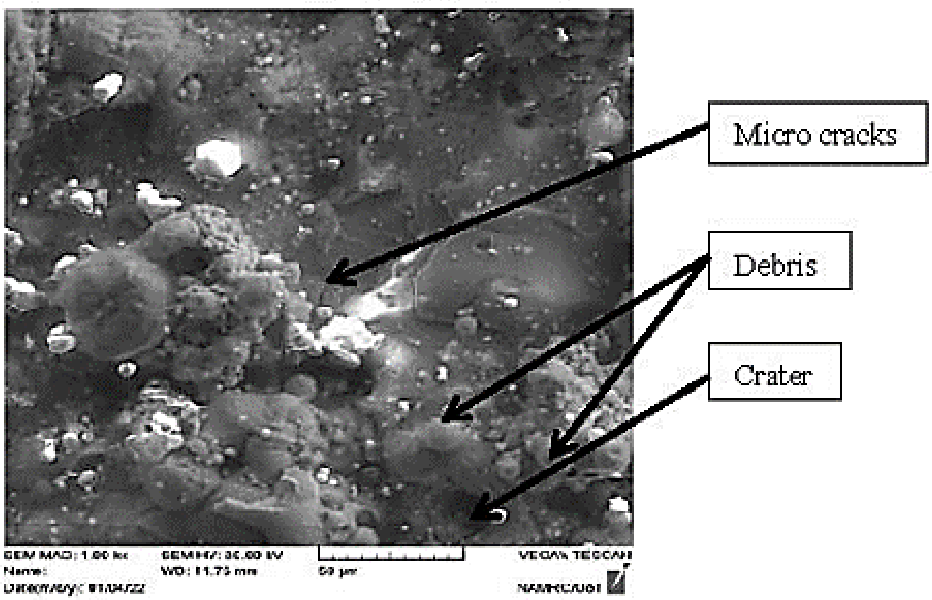


Figure 4: Microstructure of a highly energy-inputted machined surface.

information on the various ECDM hybridization machining techniques is provided by Sahil Grover and others.[17]

- MA-ECDM (Magnetic assisted Electrochemical Discharge Machining), circulation in magnetohydrodynamic phases is increased.

- LA-ECDM (LASER assisted Electrochemical Discharge Machining), enhanced hole circularity brought on by targeted electrolyte heating.

- VA-ECDM (Vibration assisted Electrochemical Discharge Machining), enhanced hydrodynamic phase electrolyte flushing.

- R-ECDM (Rotary mode Electrochemical Discharge Machining) enhanced hole circularity as much as 1500 RPM.

- PM-ECDM (Powder mixed Electrochemical Discharge Machining) refined surface finish and decreased the cracks and other defects.

- ECDG (Electrochemical Discharge Grinding) a better surface finish as a result of the gas film being thinner.[18]

Xuan Doan Cao et al. studied a hybrid technique combining of ECDM and micro grinding using polycrystalline diamond (PCD)tools. The research is summarized that micro-structures in glass specimens were first machined by ECDM and subsequently ground using PCD tools in order to enhance the surface quality. Sparks in ECDM produce rough surfaces, which can be fixed by micro grinding with PCD tools. Under the hybrid technique, the total machining time for micro grooves of 50 µm depth was less than 30% of what it would have been using the traditional grinding technique., while the best ground surface finish has been obtained. [19]

By employing composite materials based on an aluminum metal matrix reinforced with titanium carbide and intermetallic compounds of titanium aluminide Al3Ti, R. Mikheev, and I. Kalashnikov have improved the mechanical properties of synthetic composite materials. It has been determined that adding TiC particles to the aluminum matrix as reinforcement has a stronger impact on lowering the friction coefficient and wear rate. [20]

3. Types of hybrid composites materials [21]:

The essential considerations for identifying hybrid composites are thought to be the manufacturing process. Following consideration of the arrangement of constituent materials, the hybrid composites are divided into the following categories:

1. Hybrids with the same reinforcements in two (or more) layers do not interfere with one another.

2. Intraply hybrids, which combine at least two fibers in the same layers.

3. Intermingled hybrids, in which particular fibers blend together as arbitrarily as possible in order to prevent the presence of either type in high quantities.

4. Selective hybrids which have locations in which reinforcements are added over the basic laminate layer of reinforcement anywhere extra durability is needed.

5. Super hybrid composites that layered metal strips or foils that have a certain orientation. [22]

4. Categories of composite materials and its mechanical properties [3]:

1. Particle-reinforced composites, according to the particles size they are divided into:

a- The expression "large-particle" denotes the fact that continuum mechanics must be employed to describe particle-matrix interactions because they are unable to be understood at the molecular or atomic scale. The particulate phase is often more durable and stronger than the matrix in most of these composites.

b- Dispersion-strengthened composite: Particles in dispersion-strengthened composites typically have diameter that range among 10 and 100 nm and are considerably smaller. Atomic or molecular interactions between the elements and the matrix cause enhancement in strength and other mechanical properties. The little distributed particles inhibit or restrict the movements of the dislocations, whereas the matrix carries the majority of the imposed stress. accordingly, the yield and tensile strength in addition to impact resistance are increased.

2. Fiber-reinforced composites: technologically, the most significant composites are those in which the dispersed phase is in the form of a fiber. Composites materials made with fiber reinforcement that have particular properties and modulus of elasticity have been created that utilize low-density fiber and matrix materials, such as aluminum and its alloys. According to the fiber's direction, the fiber-reinforced composites divided into:

a- Continuous (aligned): The stress-strain characteristics of the fiber and matrix phases, the phase volume fractions, and the direction in which the tension stress or loading is imposed, are some of the variables that affect how this type of materials behaves mechanically. Additionally, the composite material with aligned fibers has highly anisotropic characteristics, meaning that they vary depending on the direction in which the characteristic measurement is taken. the figure 2 pointed out longitudinal direction.

b- Discontinuous and Aligned-Fiber Composites: These short-fiber composites can be made with elasticity and tensile strength modulus that are nearly ninety percent (90%) and fifty percent (50%) of their continuous-fiber counterparts, respectively, see figure 5.

c- Composites materials consisting of short, arbitrary, discontinuous fibers are typically utilized when the orientation of the fibers is random and irregular; reinforcement of this kind is schematically shown in figure 2. As opposed to tensile or compression stresses, the reduction in shear force from continuous fiber to randomly oriented strands were not as dramatic. Therefore, it is suggested to use randomly oriented strands in projects where shear is the predominant stress. It is remarkable that the magnitudes of the tensile, compressive, and shear stresses values were comparable. The identical load-bearing mechanisms and fracture mechanics for each loading situation can be used to explain phenomenon. This attribute of the material suggests that the other two strengths can be approximated using the tensile strength, which is a simpler quality to measure [23].

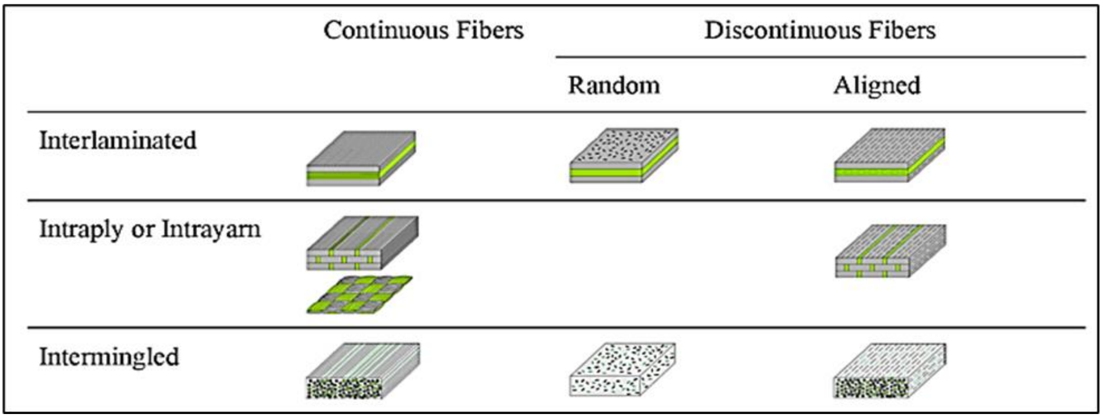
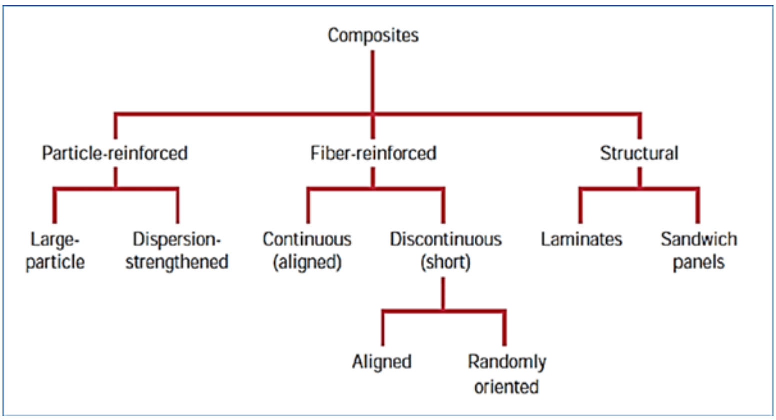


Figure 5. Hybrid fiber structures [24]

3. Structural composites (laminates and sandwich panels): they have excellent resistance against crack propagation, as in state a composite made of two aluminum laminates that each combine metal and fiber in just one layer [25].



5. An overview on the applications of hybrid composite materials:

Many composite materials have increasing uses over a wide range of high-tech medical, industrial and engineering applications. The multiplicity of types of composite materials, as well as their high mechanical properties such as micro hardness, compression strength, fatigue resistance, impact resistance, abrasion and wear resistance; in addition of chemical properties such as corrosion resistance against acids, gases and corrosive solutions; furthermore, they are very desirable in economical aspect due to low manufacturing costs, make them highly useful when compared to conventional metals and its alloys for use in many marine, aerospace and automotive structural components [26].

In industry, Wind turbine blades is the most popular prototype on hybrid composite materials. Building blades that are bigger is a crucial component of the method used by wind turbine designers to lower the price of wind electricity. The load-carrying beam and aerofoil that make up today's state-of-the-art blades are both constructed of glass fiber composites [27]. A switch to carbon fiber composites would be necessary to create blades that are larger than the ones that are currently used. When compared to a glass fiber composite blade, such a change might reduce weight by around 20–30% [28]. These weight reductions also have a knock-on effect on other parts, such the gearbox and tower. Carbon fiber blades also provide improved aerodynamic performance [29]. However, the price of a full-carbon fiber blade would be costly and out of reach. As a result, for blades longer than 50 meters, manufacturers are turning to carbon/glass fiber-hybrid composites, refer to Table 2 [29].

Table 2 Examples of wind turbines using carbon/glass fiber hybrid blades.

Manufacture	Name	Blade length (m)	Rotor diameter (m)	Capacity (MW)
LM Windpower/ Adwen	88.4 P	88.4	180	8
Vestas	V136	66.7	136	3.45
Nordex	N117/3000	n/a	116.8	3
Siemens	SWT-3.6-130	63	130	3.3
Gamesa	G132	64.5	132	5

The worldwide market for automotive composites made of polymers was valued at USD 6.40 billion in 2016 and is anticipated to reach USD 11.62 billion by the end of 2025, growing at a projected compound annual growth rate of 6.8% over the period of forecasting, according to an industry report on the subject [22]. The existence of massive amounts manufacturing of automobiles and some strict restrictions put in place in the automotive sector define the market. As shown in Figure 7 (a), the revenue generated by polymer hybrid composites for use in vehicles and the future expectation of its share of revenue are both significantly larger than those of various kinds of composites [30]. Figure 7 (b)'s consumption distribution for polymer composites shows that the bulk of composite materials are used for exterior and interior components, which justifies the need for a substantial amount of polymer hybrid composites in the automotive sector.

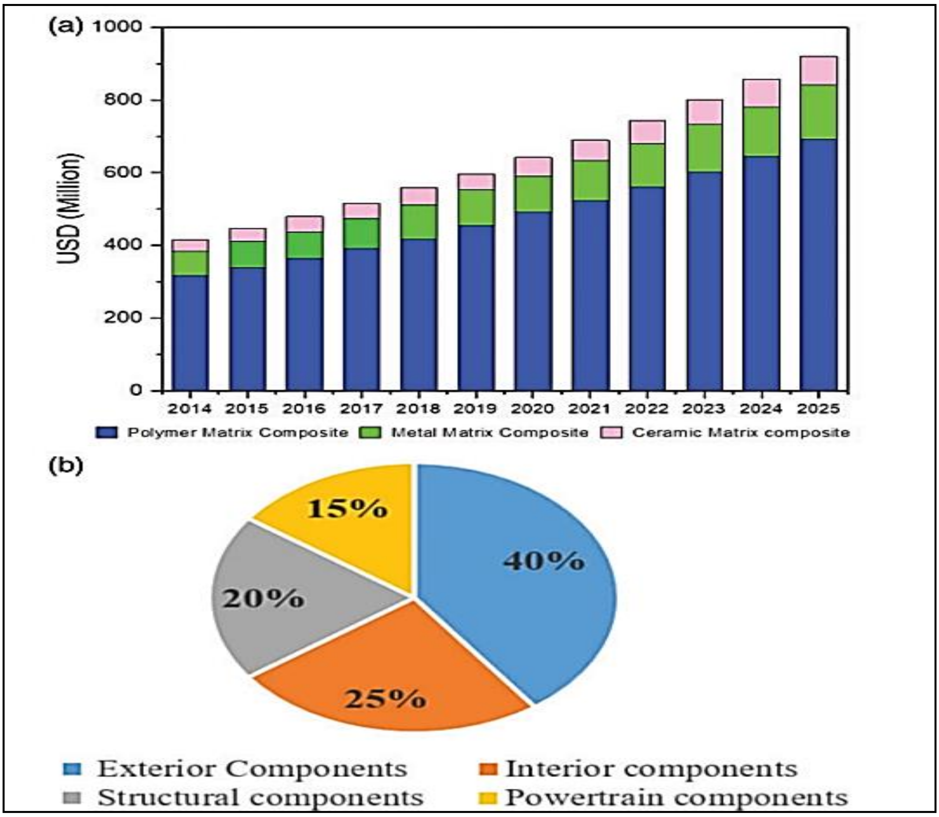


Figure 7: (a) Revenues from automotive polymer composites in the US, broken down by product, predicted through 2025. from Grand View Research [29] replicated. (b) The pattern of polymer composite applications worldwide in vehicle parts.

Using materials that are readily available in the area, Donald et al. produced a hybrid aluminum matrix composite for use in vehicle pistons [31]. Based on accessibility, price, and organic mechanical features, they decided to use carbonized coconut shells particles (CCNSp) and SiCp as reinforcement and Aluminum 6061 alloy as the matrix material [32].

• The researchers have decided that the powder metallurgy method is the most effective way to create this composite in this case.

• The powder is thoroughly combined and crammed into a steel mold built of 65HRC hardness in accordance with the ASTM requirement for the compact process [33].

• Then, using a press operated by hydraulics with a punch and die system to create the green compacts of the powder blend, the amount of powder is slowly introduced into the die having one side momentarily closed [34].

• To improve its adhesion between powder particles, the powder gets sintered in a furnace with muffles post compact.

• The material is appropriately withdrawn following the sintering procedure, and it is subsequently processed in accordance with the ASTM E228 standard for the coefficient of thermal expansion (CTE). Experimental mechanical tests are performed, including those for yield strength, Vicker hardness, and CTE. The outcomes follow a comparison to the general piston material parameters listed in table 3.

Table 3 Comparison of the obtained and general values of piston material [31]

	Tensile strength (MPa)	Hardness (MPa)
Generic value	180-230	95-135
Obtained value	172.25-207	64.97-114.87

Hybrid composite materials have a wide range in dentistry and medical fields. Initially, mechanically strengthened materials were also employed, and nanohybrid composites are highly prized in this group. They are often utilized nowadays, mostly for the direct restoration of injured hard tissue in teeth employing indirect adhesion procedures. Many of studies have been done to modify the mechanical characteristics of ingredients with nano and micro-fillers. The outcomes of the experiments revealed a substantial relationship between the kind and quantity of nanofiller and the mechanical and tribological features.

The mechanical performances of hybrid bio-composites inspected in prior experiments are revealed in Table 4.

Table 4 Mechanical properties of bio-hybrid composites [35]

Hybrid Fiber	Fiber Length (mm)	Fiber content (wt%)	Resin	Chemical treatment	Tensile strength (MPa)	Tensile Modulus (GPa)	Flexural Strength (MPa)	Flexural Modulus (GPa)
PLAF-glass	/	25	polyester	untreated	72	/	101.2	/
Sisal-glass	/	30	polyester	Alkali	130	/	150.0	/
Sisal- silk	10	/	Unsaturated polyester	untreated	17	/	33.5	/
Sisal -silk	10	/	Unsaturated polyester	Alkali	21	/	50.5	/
Jute- glass	/	14	Unsaturated polyester	untreated	/	/	/	/

Bamboo-glass	/	30	Polypropylene	untreated	18	3	34.0	3.4
Bamboo-glass	/	30	Polypropylene	MAPP	19	3	42.0	4.5
Palmyra-glass	30	41	Rooflite	Untreated	26	1.4	44.5	1.38
Palmyra-glass	40	32	Rooflite	Untreated	26	1.4	26.7	1.55
Coir-glass	20	/	Phenolic	Untreated	22	3.8	53.4	4.8
Coir-glass	20	/	Phenolic	Alkali	26	4.3	68.3	5.6
Sisal-glass	/	Silk fiber:20 Glass fiber:10	Polypropylene	Untreated	30	2.3	66.7	4.03
Roystonea regia glass	7	Roystonea regia fiber:15 Glass fiber:5	Epoxy	Untreated	32	2.4	40.1	3.9
Glass-sisal	30	/	Polyester	Untreated	176	/	/	/
Sisal-glass	35	/	epoxy	Untreated	69	/	/	/

The researches show that far more enduring and aesthetically pleasing tooth fillings are possible when combining bio-composite substances with nanohybrid fillers.

In addition to being employed as restorative and bonding materials for reconstructing damaged tissues through indirect adhesion procedures, teeth composite materials should be used for the immediate healing of injured hard tissue in dentistry. that far more enduring and aesthetically pleasing tooth fillings are possible when combining bio-composite substances with nanohybrid fillers.

In addition to being employed as restorative and bonding materials for reconstructing damaged tissues through indirect adhesion procedures, teeth composite materials should be used for the immediate healing of injured hard tissue in dentistry. Dental fillings' functional and toughness attributes are enhanced by around 15% when nanofillers with particle sizes between 0.005 and 0.04 µm are used instead of macro-fillers with particle sizes between 0.2 and 70 µm.

The employed nanofiller significantly impacts the capacity to stand up to wear and general erosion. Its size varies from roughly 3900 µm2 to more than 4500 µm2 (see Figure 5) [36].

Figures 8 and 9 depict the mass wear in mg and mm2 of the investigated specimens, respectively, following tribological tests.

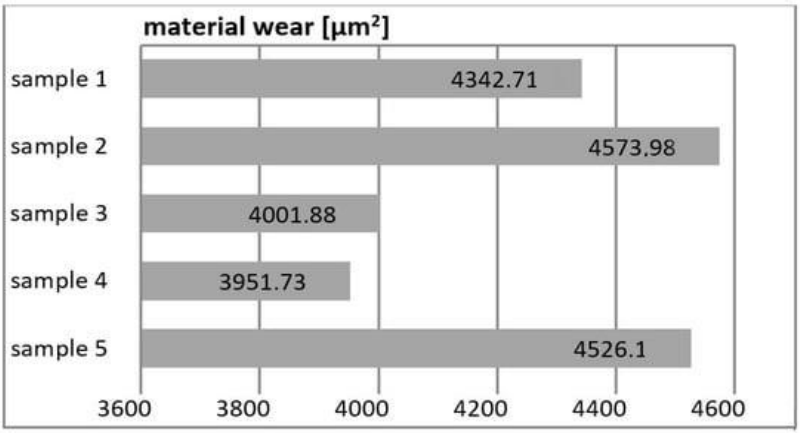


Figure 8: Wear of specimens

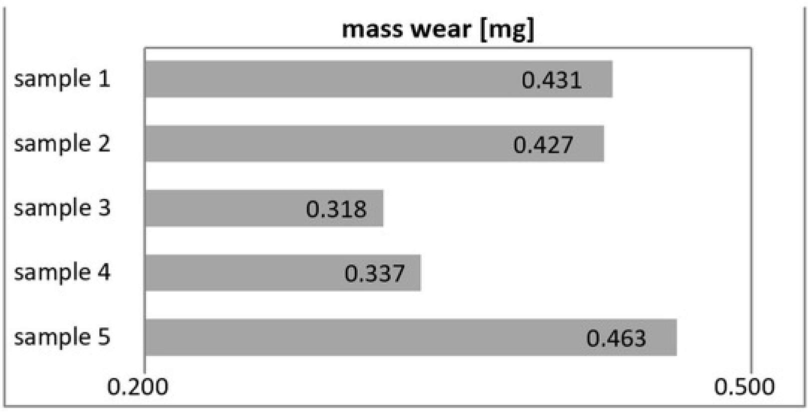


Figure 9: Mass wear of specimens

In the beginning stages of this study, it was discovered that all of the examined specimens' friction coefficients raised through the tribological examinations.

Thru the hardness tests, the results display enhancement of both ball and Vickers method. In the case of the ball technique, it was between 35.1 MPa to 62.5 MPa. The range of values of changes in the Vickers technique was between 410.7 MPa to 727.7 MPa. [36]

From the side of architectural and civil engineering it was noted that hybrid composite materials are growing owing to many of their benefits. Economics and sustainability (operations including recycling and restoration) should be taken into account throughout the research and development process of carbon-fiber reinforced polymers (CFRP). [37]

Hybrid Composite Synthetic Concrete (HCSC) is a common hybrid composite material, which is used in structural deck repairs, stiffening overlays, substructure, link slabs. Hybrid Composite Synthetic Concrete (HCSC) is a high performance, structural, basalt fiber reinforced polymer concrete material with hybrid co-polymer resin binder and pre-blended basalt fibers with graded aggregates specifically formulated to meet unique and demanding field-cast concrete applications in bridge construction with an emphasis on bridge deck elements like precast closure pours, large full depth bridge deck patching, full depth bridge deck joints, composite deck stiffening overlays, orthotropic steel deck bonded thick wearing surfaces and more. [38]

Another familiar of composite materials in construction and building material is the Cold-Formed Steel (CFS) truss composite floor constructions with Autoclaved Lightweight Concrete (ALC) or Profiled Steel Sheeting-Concrete (PSSC) blocks are existing and represented in figure 10 [39]. The strength of cement concrete can be increased via income of steel shafts or rebars, that are surrounded into raw cement [1]. Figure 10 is illustration implantation the rebar in the cement.

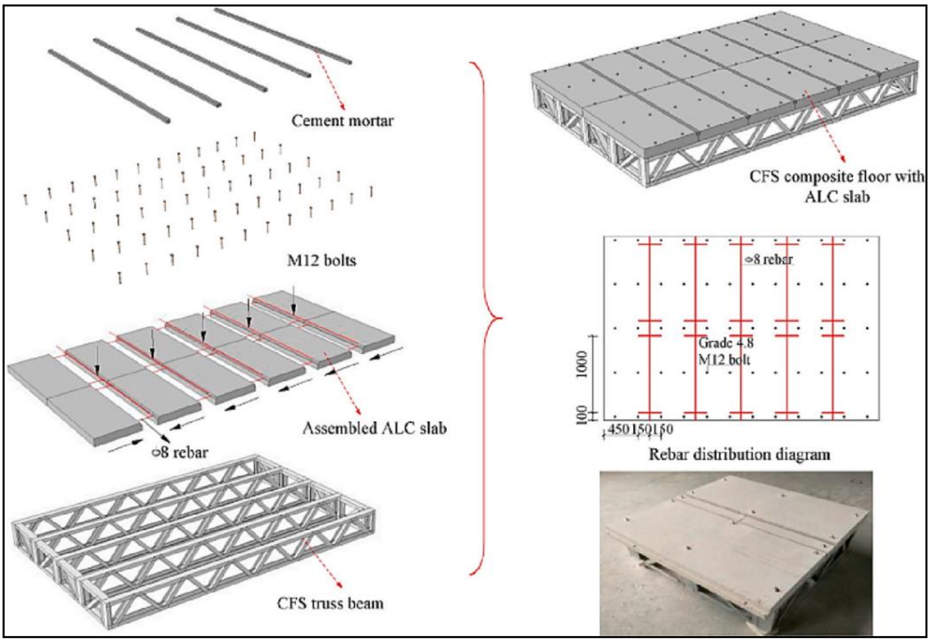


Figure 10: CFS composite floor with ALC slab [38].

6. Conclusion:

The outcomes that follow can be reached with regard to the numerous uses of hybrid composite materials

Composite materials such as aluminum alloy matrix with 10% SiC ceramic particles, or (70% Cu-30%Ag) have been developed the performance of ECDM process, by higher MRR with lower TWR and value of SR.

The investigates demonstration that using nanohybrid fillers in composite materials allows for much more hard-wearing in dental fillings.

In dental fillings, the increase in wear and abrasion resistance of basically related to the nanofiller used, it increased 3900 μm2 up to over 4500 μm2. And the hardness enhancement from 411.7 MPa to 726.7.

To create the hybrid composites, glass and carbon fibers were mixed and added to epoxy resin, which demonstrated great strength. Which is used in various parts of automotive, like car exterior structures, piston and others.

the increased usage of CFRP, HCSC, PSSC and CFS in the civil engineering applications instead of conventional concrete, which lead to an increase in the expiry date of heavy construction products and equipment and thus promotes the economic development.

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