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Machinability of Polymeric Composites and Future Reinforcements—A Review

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Abstract

This paper reviews the machinability and mechanical properties of natural fiber-reinforced composites. Coupling agents, operating parameters, as well as chemical treatment effects on natural fiber-reinforced composites' machinability are also reviewed. Moreover, the impacts of fibers' physical properties on the machinability of the composite are mentioned. Fiber volume fraction (V_f), fiber orientation as well as chemical treatment effects on mechanical properties are also defined. Conclusively, the effect of fibers' physical properties as well as mechanical properties is described. It was discovered that chemical treatment of natural fibers improved their compatibility with the matrix by removing their surface tissues, increasing the roughness average (Ra), and reducing moisture absorption. Also, the Orientation of the fiber plays an important role in controlling the mechanical properties of the composite. Moreover, some physical properties of the fibers, including quality of fiber distributed in the matrix; fiber size, length, and diameter; moisture absorption; porosity and the way fibers break during compounding with the matrix, were found to affect the mechanical properties of the composites formed.

Keywords

Machinability, Natural Fiber, Composites, Chemical Treatment, Operating Parameters

1. Introduction

Polymeric composites nowadays are gradually being utilized in some industrial applications for replacing metals as well as metal composites, which is a positive development [1] [2]. For example, some metal components of aircraft were also replaced with carbon/epoxy composite components. The use of fiber/polymer composites in marine applications has also been discovered; numerous metal parts are also being replaced with fiber/polymer composites in ships. According to Hung *et al.* [3], suitable tools in a conventional machining procedure are also required for machining metal matrix composites. Synthetic fiber composites, including carbon fiber and glass fiber composites, on the other hand, present a significant challenge due to the fibers' refractoriness, extreme hardness, as well as inert nature to machinability in terms of their bearing strength, material removal rate, thrust force, cutting power, *Ra* (roughness average), and delamination size. Anisotropic and Heterogeneous properties are present in them [4] [5] [6]. Moreover, abrasive properties of synthetic fibers cause poor surface finish as well as rapid tool wear [7] [8].

To ensure the effectiveness of the machining procedure, this is essential that the cutting parameters, as well as the tool, are chosen correctly. Nevertheless, several researchers reported that over the past few years [9]-[20], the machining parameters' effect for example V_f, fiber orientation, drill diameter, speed, and feed have a significant impact on such materials' machinability. It has been found, however, that less work was done on natural fiber-reinforced composite materials' machinability for machining power, cutting pressure, tool life, cutting power and force, material removal rate, cutting forces, Ra, along with tool wear than has been done on synthetic materials' machinability. It is now widely recognized that synthetic fibers are extremely rough materials, which can cause important damage to machining tools as well as machines. Fibers are hair-like class materials that can be separate or continuous. It can be categorized into 2 main types: synthetic and natural. Natural fibers, namely plants, minerals, and animals, come from 3 major sources. Natural plant fibers have been used for protection and warmth for the first time more than 5000 years ago. In particular, because of the rise in synthetic fibers, the natural fibers sector lost the majority of its market share after World War II [7] [8] [21]. Synthetic fibers are having a serious negative impact on process machining and manufacturing, including high energy consumption, non-recyclability, high cost, non-renewability, along with high abrasiveness, CO_2 emission, along health problems when inhaled. Such limitations were greatly utilized by the supporters of natural fibers [21] [22] [23] [24].

Numerous researchers are now working on replacing synthetic fibers with natural fibers to comply with new environmental regulations as well as petroleum resource depletion [7] [25] [26] [27]. In 2006, the "United Nations' Food and Agriculture Organization declared 2009 the international year of natural fibers". This year's campaign was focused on enhancing global awareness of natural fiber and market demand [28] [29] [30]. Due to their higher characteristics, like renewability, abundance, low cost, non-toxicity, low weight, non-abrasiveness, biodegradability, low environmental effect, as well as CO_2 emissions, many efforts have been made over the last few years (2005-2021) to use natural fibers (nature fibers) to enhance polymer composites [31] [32] [33] [34] [35]. In addition, natural fibers are a commodity based on prices, causing less damage to the equipment and molding, a better finish, flexibility, and high energy consumption (bending instead of fracturing) [7] [20] [36]. Furthermore, the special surface micromorphology and low-cost benefits of each fiber, which also grew rapidly around the world to the detriment of synthetic products, have attracted the most significant benefits to the market for natural fibers [37] [38] [39]. However, the "low melting point, poor wettability, low resistance to moisture absorption, and lack of good interfacial adhesion" that results in debonding with age, have been identified as the main disadvantages of natural fibers that make them a less attractive option [35] [39] [40].

In polymeric composites, a variety of plant fibers extracted from a variety of plants were utilized as reinforcements, including palm tree fibers [41] [42], flax [43], hemp [37] [38] [44], jute [20] [39] [43], wood fiber [40], rice husks [45], wheat [46] [47], barley [47], oats [47], agave [48], cane (sugar and bamboo) [49] [50], vakka [42], kenaf [44] [51] [52], ramie [53], oil palm empty fruit bunch fiber [54], sisal [55], coir [56], bamboo [42] [57], roselle [55], banana fiber [58] and pineapple leaf fiber [10].

Most of the studies that have been done on natural fibers in polymeric composites were done for investigating natural fibers' effects on the electrical, thermal, dynamical, tribological, mechanical, physical properties of polymeric composites. Fiber composite's mechanical properties depend on several parameters, for example, composite structure, fiber's mechanical and physical properties, fibers' V_f, fiber's surface characteristics (for interfacial adhesion), as well as fiber orientation. The impacts of every parameter on composites' mechanical properties must therefore be discussed in detail.

The fact that most Polymer matrices are lacking in good adhesion is the major problem in natural fiber-reinforced composites' processing. This can prevent natural fibers' hydrophilic nature from interlocking [10] [59] [60] and can thus adhere to hydrophobic matrixes. For preventing this, the fibers' surface must be adhesively modified for improving composite machinability [61] [62] [63] [64]. Khan and Kumar [10] examined the short agave fiber-reinforced epoxy composites' machinability for fiber-matrix interaction for alkali-treated as well as untreated (5%) fibers. It was discovered that the treated composites had rough surfaces that resulted in improved interlocking among the matrix and fiber and raised the contact area. The untreated composites, on the other hand, were found to have voids. Valadez-González *et al.* [61] revealed qualitatively identical findings to those obtained by the authors in examinations of the influence on fiber strength of the matrix bonding of reinforced composites with natural fiber-surface treatments.

Athijayamani, Thiruchitrambalam [55] investigated the "machinability of an alkali-treated natural fiber (sisal and roselle) hybrid polyester composite in terms of weight loss." 10% NaOH (sodium hydroxide) solution treatment was applied to fibers for varying periods (2, 4, 6, and 8 hours). Gradual weight loss has been seen as the wear test time (4, 8, and 12 minutes) was increased, and composite samples treated with alkali outperformed the untreated composite samples in terms of wear performance. This could have occurred as a result of the alkali treatment, which removed moisture from the fibers and showed rising results in the interfacial bonding strength between matrix and reinforcement, as per a few researchers. Nam, Ogihara [54] examined the alkali-treated as well as untreated "(5% NaOH) coir fiber-reinforced poly (butylene succinate) biodegradable" composites' machinability in terms of the *Ra* (roughness average). It has been reported that treating the fiber with 5% alkali for 72 hours increased the *Ra* along with cellulose amount exposed on the fiber surface, which in turn strengthened the mechanical connection between matrix as well as fiber and resulted in improved machinability. Kabir, Wang [65] reported similar results for the o alkali treatment's effects on *Ra* of hemp fiber-reinforced sandwich composites, and these findings are qualitatively the same as to report.

2. Mechanical Characteristics of Natural Fiber Polymer Composites

Natural fibers were utilized in the past in certain industries that dealt with door inner panels, seat backs, as well as roof inner panels [16] [66] [67] [68], among other things. Mallick [69] has stated that natural fibers have recently risen to the top of the list of engineers, scientists, as well as researchers' priorities as the elective material for FRP "Fiber-Reinforced Polymer" composites reinforcement. It is becoming more popular to use natural fibers because they have several advantages over synthetic fibers, for example, their low cost as well as non-abrasiveness. Natural fibers affect fiberglass-reinforced plastics' properties, and they may be utilized for improving the material's tensile strength. Enhanced interfacial bonding, as well as a raise in Young's modulus of the composite mixture, are achieved through chemical modifications [15]. Natural fibers have assumed a central role in the textile industry because of their favorable mechanical properties as well as their low cost, high specific strength, non-abrasiveness, biodegradability, as well as environmental friendliness. Because of their numerous benefits over conventional fibers, for example, carbon as well as glass fiber, they are frequently used as substitutes [70].

Natural fibers have an impact on the nature of polymeric composites in several ways, including altering polymers' tensile properties [46] [47]. Irrespective of which polymer type is utilized, polymer's tensile properties are modified by altering the interface adhesion between matrix and fibers [71]. The interfacial matrix-fiber bonding of natural fiber composites may be enhanced through the utilization of various chemical modifications [72]. When it comes to increasing the natural fiber's strength, it is necessary to increase its content to a maximum or optimal level [59]. Also, Ma, Yu [73] has reported, the best natural fiber composite's Young's modulus has been achieved by determining the optimum fiber content utilized in the mixture. For example, increasing the fiber loading of FRP results shows a significant rise in material's tensile strength as well as Young's modulus. For composites containing 10 wt% coir fibers, an improvement of more than 34% and 22% was attained in the tensile strength and elastic modulus, respectively [74]. Mallick [69] in his book, summarized the jute fibers, flax sisal, and hemp's mechanical properties, giving overall information regarding the fibers' elongation and modulus as well as tensile strength. As additional information and analysis sources, the following sections examine the chemical treatments' effect on the fibers and composites' mechanical properties, including fibers' orientation and volume fraction.

2.1. Effect of Chemical Treatment

This is recognized that natural fibers have a problem when it comes to their compatibility with a matrix of any kind (interfacial adhesion). Primarily this issue is caused by the existence of tissue on the fiber surface, which reduces fibers interlocking with the matrix and causes them to loosen from the matrix. Several studies have found that untreated fibers can cause pull-out mechanisms (such as tensile, flexural mechanisms, and tribology) to occur under loading conditions. A few techniques, including fiber's chemical treatment, may be utilized to overcome the fiber adhesion problem to the matrix at the interfacial interface [37] [38] [41] [43] [47] [48] [52] [55] [61] [62] [75] [76].

Chemical treatment is the cleaning procedure of fiber's surface, eliminating some tissue, decreasing the moisture absorption level along with rising the *Ra* [48] [52] [59] [60]. Numerous writers have studied the chemical treatments' effect (for example $CaCl_2$, Ca $(OH)_2$, lime water, acetylation, bleaching, ethylenediaminetetraacetic acid, polyethyleneimine, and NaOH) on fibers' interfacial adhesion with a matrix that in turn, affects the composites' properties [37] [38] [41] [43] [48] [52] [53] [55] [56] [58] [61]. In chemical solution, fiber's immersion is the most widely utilized technique for chemically treated fibers. The efficiency of the chemical treatment depends upon the solution's concentration, the immersion duration, fibers' surface characteristics, and the type of fiber used [55] [63] [64] [77].

Using sisal and roselle fiber, Athijayamani, Thiruchitrambalam [55] studied the immersion duration impacts (2 - 8 hours) in alkali (10%) on the hybrid polyester composites' mechanical properties. According to the findings of this study, raising the immersion duration resulted in a 59 percent and a 47 percent rise in composite's flexural strength and tensile strength, respectively. These were because of the significant enhancement in fibers' interfacial adhesion with a matrix that occurred as a result of the removal of the outer layer of tissue from the fiber surface following the procedure. Throughout tensile loading, this increased the fiber's adherence to the matrix as well as allowed it to carry a portion of the load. However, this was discovered that the untreated fibers have been found unable to support the load. As previously reported [48], similar results were obtained when short agave fibers had been treated for alkaline as well as utilized to reinforce epoxy composites. This is possible to argue that the increased duration of the treatment caused damage to the fibers' tissue, resulting in a weaker interfacial adhesion between matrix along with fiber.

A study conducted by Kabir *et al.* [65] observed the hemp fiber-reinforced sandwich composites' mechanical properties had been treated in 3 distinct chemical ways (alkalization, acetylation, and salination). According to the findings, fibers treated with alkali and pre-soaked in 8% NaOH had more tensile strength (111.05 MPa) as compared to untreated fibers (84.06 MPa) (**Figure 1**), and this has been because of the removal of lignin, hemicelluloses, along with other cellulosic constituents from the fiber by the treatment. As a result, the fiber as well as the matrix adhered to one another more effectively. The use of saline, on the other hand, resulted in a fiber surface that was coated. The adhesion quality between the matrix and fiber was lowered as a result of this. Lastly, acetylated fibers exhibited a brittle surface on their outer surface. In chemically treated natural fibers' case, numerous authors have reported similar findings [37] [39] [69].

Edeerozey, Akil [52] investigated some impacts of treating kenaf fibers with NaOH at various concentrations (3 percent to 9 percent) on fiber's tensile strength. The researchers concluded that 3 percent NaOH has been ineffective at removing impurities. The most effective concentration for treating the fiber has been 6 percent NaOH, which completely removed the impurities from the fiber. The increased concentration of NaOH attacked the fiber's primary structural components, resulting in the appearance of more grooves on its surface. The fiber's strength was further reduced as a result of this. As a result of increasing the concentration of NaOH, the tensile strength began to decline (**Figure 2**). Fibers treated with 6 percent NaOH show the highest tensile strength, whereas untreated fibers show the lowest, with 215.4 N/mm^2 for the highest tensile test result. The removal of impurities was responsible for the increase in strength. Researchers Eichhorn *et al.* [68] discovered something similar when they used kapok fibers to treat them with a high concentration of a chemical solution.

Saha, Manna [61] examined two different chemical treatment methods. First, fibers have been immersed in 0.5 - 18 percent NaOH for varying periods, ranging from 30 min - 24 hours at 30˚C. While the other method involved immersing the fibers in 0.5 - 18 percent NaOH for 30 minutes period time to 8 hours at 30˚C, depending on the concentration. When 0.5 percent alkali/steam treatment has been applied to the fibers, this was discovered that the tensile strength (610 MPa) increased by 65 percent (from 370 MPa) when compared to the untreated fibers (370 MPa) (**Figure 2**). It has been because of fiber separation as well as the removal of non-cellulosic materials.

Alawar, Hamed [41] studied the date palm tree fibers' elongation at break, mechanical properties, tensile strength, young's modulus, subjected to various chemical treatments (0.3 - 1.6 percent HCl and 0.5 - 5 percent NaOH). This has been shown to enhance the surface morphology of fiber surfaces by cleansing fiber surfaces of contaminants with a 1 percent NaOH treatment. In comparison to the raw fibers of 200 MPa as well as the young module, the tensile resistance raised to 800 MPa, up to 160 GPa compared with raw fibers of 8 GPa (**Figure 3**). On the other hand, the surface morphology was observed to be distorted and the tensile strength reduced to 105 MPa when HCl treatment has been utilized. In the last, the treated fibers presented higher resistance to degradation (42 percent) than the raw fibers (35 percent). Usually, increased concentrations of HCl weakened the fibers. Moreover, Table 1 summarizes some of the recent works that study the effect of chemical treatment of natural fibers on mechanical characteristics of natural fiber polymer composites.

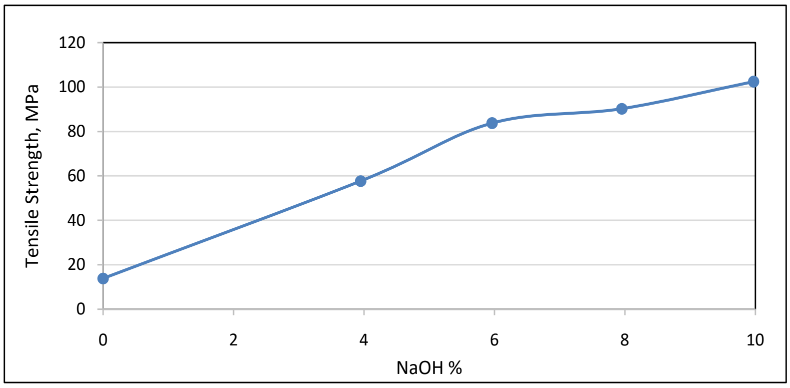

Figure 1. Tensile strength v. NaOH percentage [41] [48] [55].

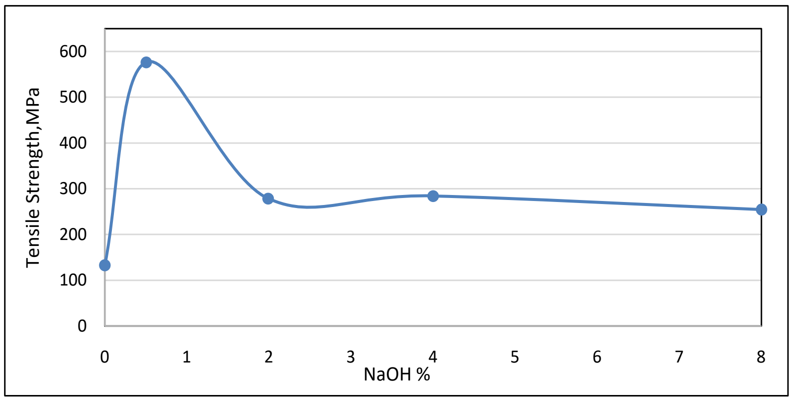

Figure 2. Tensile strength v. NaOH percentage [61].

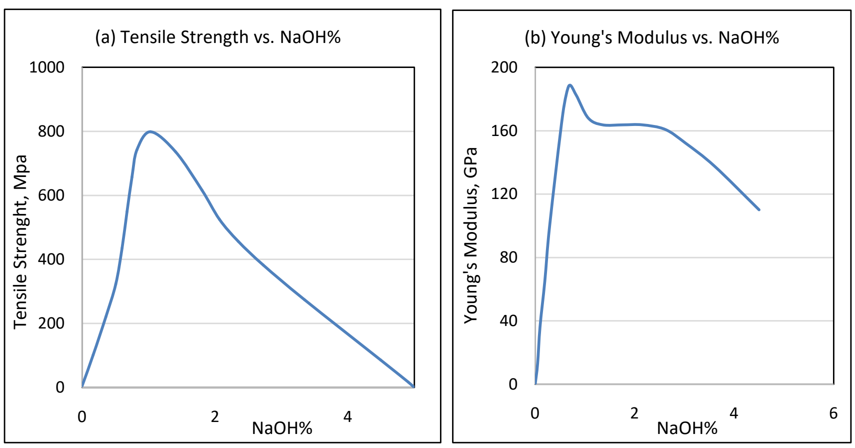

Figure 3. Influence of NaOH on the tensile strength and modulus of elasticity of palm tree fibers [41].

Table 1. Summarizes some of the recent works that study the effect of chemical treatment of natural fibers on mechanical characteristics of natural fiber polymer composites.

Fiber	Matrix	Treatment	Remarks
Sisal and Roselle [69]	Hybrid Polyester	• NaOH	Raising the immersion duration resulted in: • Flexural strength increases by 59% • Tensile strength increases by 47%
Agave [48]	Epoxy	• NaOH	Increased duration of the treatment caused: • Fibers' tissue damages • Interfacial adhesion decreases
Hemp [65]	polyester	• NaOH • Acetylation • Salination	• Fibers treated with 8% NaOH had more tensile strength as compared to untreated fibers. • Saline treatment led to lower the adhesion quality between the matrix and fiber
Coir [66]	Polyethylene	• Silane (0.5 wt%) • NaOH (1.6 mol/L) • Dodecane bromide (C12) (3 mL)	• Silane increased adhesion force by 12% • NaOH decreased adhesion by 4% • C12 increased adhesion force by 4%
Betel nut [16]	• Polyester • Epoxy	• HCl 4% • HCl 6% • NaOH 4% • NaOH 6%	• 6% NaOH with polyester increased adhesion force by 130% • 6% NaOH with epoxy increased adhesion force by 112%
Banana [67]	• Polylactide (PLA)	• NaOH 10%	• Interfacial adhesion increased by 93%
Shalwan and Yousif [24]	• Epoxy	• 6% NaOH	• Highly enhanced the interfacial adhesion compared to the untreated fibers

2.2. Effect of Fiber Orientation

Fiber orientation plays an essential part in the control of natural FRP composites [13] [21] [30] [32] [59] [78] [79] [80] irrespective of the marked influence of fiber processing on composites' mechanical properties, as stated in the last section. Valadez-Gonzalez, Cervantes-Uc [56] investigated the effect on mechanical properties (flexural as well as tensile strength) of henequen fiber-reinforced high-density polyethylene of the fibers (longitudinal or transverse) and treatment with 2 percent HAO (HDPE). In terms of modules of elasticity, tensile strength, as well as flexure strength, this paper demonstrated that the longitudinal orientation had approximately 90 - 95 percent higher mechanical properties than transverse orientation (**Figure 4**). Fiber's longitudinal orientation, combined with chemical treatment, increased the fibers interlock in a composite that resulted in a better transversal mechanical characteristic than those in the untreated fibers.

Brahim and Cheikh [13] investigated the effects of polyester composite's mechanical properties on fiber orientation (0˚ - 90˚) of unidirectional Alfa fibers (modulus of elasticity and tensile stress). The fibers were extracted from the Alfa plant by soda procedure whereby the plant stem has been heated for 2 hours with a NaOH solution of 3% at 100˚C temperature and then bleached with a NaClO solution of 40% for 1 hour. The composite's mechanical properties (modulus of elasticity and tensile stress) have been found weakened with the increase in the angle of orientation from 12.3 to 5 GPa and from 150 to 18 MPa.

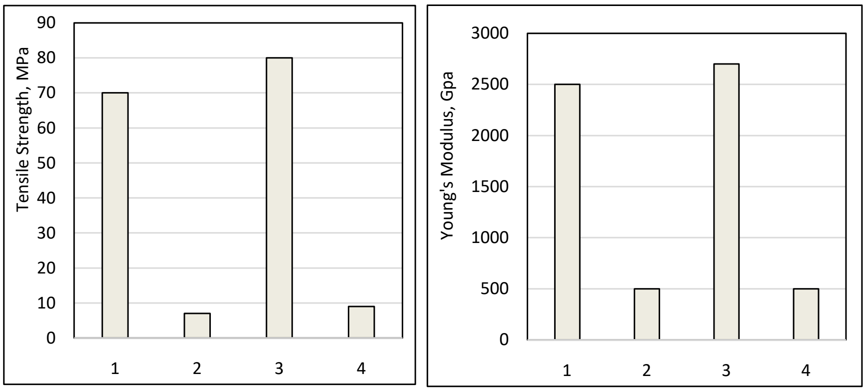

Figure 4. Influence of fiber orientation on the mechanical properties of henequen fiber/HDPE composites. (1) "Untreated Longitudinal, (2) Untreated Transverse, (3) Treated (two percent NaOH) Longitudinal, (4) Treated (two percent NaOH) Transverse [81].

This may be described by the fact that if the fibers have been orientated in the direction of load (0˚) this would cause the load to be distributed along the entire fiber's length. Moreover, if load directions had not been parallel to fibers, the load did not spread throughout the whole fiber, thus reducing the value.

Jacob, Thomas [82] examined the impact of the orientation fiber (0˚ - 90˚) on the tensile strength of the natural rubber composite sisal/oil palm hybrid fiber. They found that when the fibers are longitudinally oriented (0˚), the maximum tensile strength (8 MPa) is achieved. By contrast, tensile strength is reduced to 4 MPa when the angle for the orientation of fibers has been raised to 90˚. When the fibers are lined up (longitudinally) in a force direction, stress is transferred evenly. Moreover, they cannot distribute a lot of stress when fibers are aligned (transversely) with load direction.

De Albuquerque, Joseph [15] examined the fiber orientation's effect on the jute roving reinforced polyester composites' tensile strength. This has been observed that tensile strength is directly proportional to the fiber content in the transversal direction because, with the rise in fiber content from 0 percent to 30 percent by weight, tensile strength also raised from 40 MPa to 65 MPa. On the other hand, tensile strength is inversely proportional to fiber content in the longitudinal direction as tensile strength reduced from 40 MPa to 10 MPa with the same rise in fiber content. Such results may have been because of the obstacles presented by the longitudinally orientated fiber, which inhibited the stress distribution throughout the matrix, therefore causing a higher stress concentration along with inadequate mechanical properties.

2.3. Effect of Volume Fraction

It has been shown that the fiber V_f (such as the fiber's concentration in composite) has a significant impact on composites' mechanical properties. This was also reported that some increases in the fiber's V_f [43] [81] [83] can result in an improvement in the fiber's mechanical properties. Above a specific level, high V_f can cause fiber clotting, as well as applied loads, which cannot be distributed consistently that limiting the mechanical properties [70]. Hence, strengthening the composite depends on the optimization of a fiber's V_f value [8] [14] [24] [71] [72] [73] [74] [84]-[89]. Müller, Laurindo [78] and Bras, Hassan [79] examined cellulose fibers' (V_f) effects on starch-based composite's mechanical properties. This research demonstrated that raising the fiber's volume in composite resulted in a rise in the reinforced composites' elasticity modulus and tensile strength above that of the neat composite.

Brahim and Cheikh [13] evaluated as well as compared to synthetic composites based on glass fiber for fiber V_f effect (0% - 44%) on Alpha/polyester composites' mechanical properties (longitudinal stress). The findings noticed that the composite's mechanical properties increased by up to 44% with V_f increases (**Figure 5**) and have been closely related to synthetic fiber composite (glass) at similar V_f. Yousif [70] investigated the V_f effect (0 percent to 60 percent) on polyester composites' mechanical properties from oil palm fruit fibers.

Yousif [70] examined the polyester composites' mechanical properties for the impact of V_f (0 - 60 percent) from oil palm fibers. The conclusion is that the volume fraction was increased by around 110% compared to neat polyester, resulting in the 41%rise in tensile strength. The increase in composite's compression strength to 38% resulted in a 30 percent increase in the V_f. Such results had been caused by strain distribution or uniform stress in the composite. But the clotted fiber cannot be distributed equally at higher fiber loading, and the load applied. Likewise, the composite's tensile strength decreased as the fiber V_f increased (**Figure 6**).

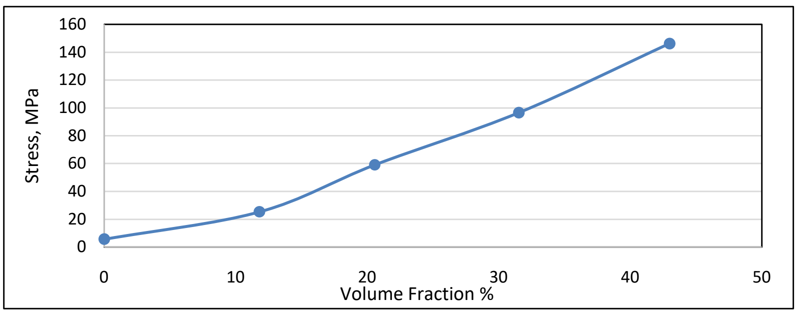

Figure 5. Fiber volume fraction effects on Alfa/polyester composites [13].

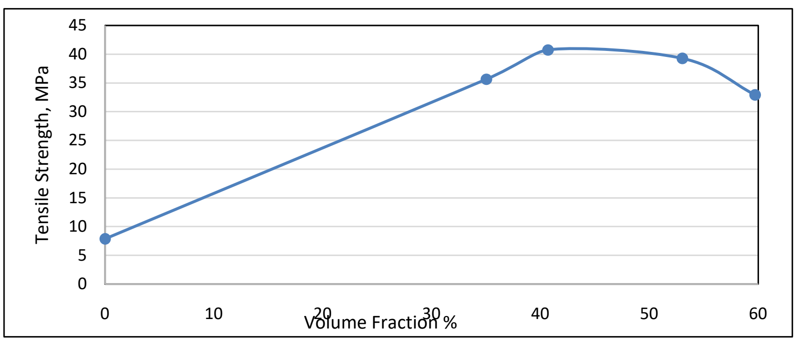

Figure 6. Fiber volume fraction effects on the tensile strength of oil palm fruit fibers/polyester composites.

2.4. Effect of Physical Properties of Fibers

Various research on fibers' physical properties was conducted which affect the natural composites' final properties. It thus includes the fiber's quality of the matrix, length, size as well as diameter of the fiber, porosity, moisture absorption as well as how fibers break down with matrix [4] [17] [90]-[97]. Due to concentrated mechanical and thermal stresses, fibers are subjected to this mixing process during which they break up and thus lose some of their reinforcing action. However, in the composite's mechanical property, as mentioned by Le Duc, Vergnes [98], the fiber's aspect ratio, that is the ratio between diameter (D) and longitude (L) also plays a significant part.

Brahmakumar, Pavithran [99] examined the impact of fiber composites' mechanical properties (5 - 25 mm) as well as fiber content (10 - 27 percent) (strength, elongation, and modulus). Fiber length rises from 5 mm to 20 mm reportedly resulted in an increase of 52 percent, 31 percent, and 26 percent of tensile strength, elongation, and tensile module respectively. Although, over 20 mm length, tensile modulus reduced by 13% while tensile strength reduced by 8%), although the elongation value was no longer modified. Furthermore, an increase of 10% - 25% in the fiber content caused an increase of 48% tensile resistance along with 53% tensile modulus, whilst an increase of 50% in the elongation value has been observed. However, over and above 25% fiber content, declines were observed in tensile modulus and tensile strength, and no changes were observed in elongation value (up to 5% and 14% respectively).

Beg and Pickering [8] have examined the impact of fiber length (0.95 mm to 3.07 mm) on mechanical characteristics (impact strength, failure pressure, Youngs' modulus along with tensile strength) of kraft, fiber-enhanced polypropylene compounds. The decrease of the fiber length resulted in an increase in the tensile force from 37 MPa to 43 MPa, Yung modulus from 3.8 GPa to 4.6 GPa and impact power from 5.6 kJ/m^2 to 6.5 kJ/m^2, while stress failure reduced between 2.47 and 1.91 percent. Such mechanical characteristics changes may be caused by the decreased reinforcement efficiencies, that Harper, Turner [100].

Yemele, Koubaa [101] utilized a factorial design for examining the impacts of bark fiber content (trembling aspen bark along with black spruce bark) and size (0.50 - 1.00 mm coarse; 0.25 - 0.50 mm medium; 0.18 - 0.25 mm fine) on bark/HDPE composites' tensile strength as well as flexural modulus. It was found that the fine fiber of trembling aspen bark and black spruce bark had the lowest L/D ratios (3.83 and 8.85, respectively) and that the coarse fiber of trembling aspen bark and black spruce bark had the highest L/D ratios (10.68 and 13.83 and, respectively). The experiments' results revealed that rising the material's fiber content, resulted in increases in flexural modulus as well as tensile strength. More importantly, increasing the length of the fibers increased their elasticity and strength while decreasing their toughness along with tensile strain at failure, indicating that fiber content impacts on mechanical properties have been more essential than the impact of fiber size on mechanical properties.

Migneault, Koubaa [85] investigated the L/D ratio effect (8 - 21.3), with two treatment techniques, on tension and flexural module of wood-plastic composites (injection molding and extrusion). In both processes, the fiber L/D ratio had a similar impact on tensile strength as well as a flexural module. Fiber L/D ratio increased in both, but to a different extent. The injection molding process associated with increasing fiber size, however, resulted in improved mechanical properties than the extrusion procedure. This disadvantage is usually related to fiber fracture in the extrusion process, as other studies have indicated [49] [102].

2.5. Recommendations and Main Points Extracted from the Previous Discussions

It was discovered that chemical treatment of natural fibers improved their compatibility with the matrix by removing their surface tissues, increasing the Ra, and reducing moisture absorption. This resulted in improved mechanical properties of the composites [37] [38] [41] [43] [47] [48] [52] [55] [61] [62] [75]. The duration of chemical treatment was vital. The mechanical properties increased with a longer duration of treatment, but they would peak to a maximum and then fall. The usual chemical used was NaOH, at different concentrations.

Orientation of the fiber also plays an important role in controlling the mechanical properties of the composites [9] [17] [19] [81] [93] [101] [103]. Herrera-Franco and Valadez-González [81] and Jacob, Thomas [82], respectively, found that longitudinal fiber orientation provided much higher tensile and flexural strengths than its traverse orientation counterpart. It was also reported that mechanical properties could be enhanced by increasing fiber V_f [13] [42] [71]. However, V_f above a certain level causes fiber clotting, thus the applied loads cannot be distributed evenly, which leads to a decrease in mechanical properties [70]. Therefore, the optimization of a fiber V_f value is necessary for strengthening the composite [8] [14] [17] [71] [72] [73] [84] [85] [86] [87] [88].

Some physical properties of the fibers, including quality of fiber distributed in the matrix; fiber size, length, and diameter; moisture absorption; porosity and the way fibers break during compounding with the matrix, were found to affect the mechanical properties of the composites formed [4] [70] [85] [90] [93] [104] [105]. Moreover, the aspect ratio of the fiber (L/D) also plays an important role in the mechanical properties of the composite, as mentioned by Le Duc, Vergnes [98]. Beg and Pickering [8] found that a decrease in fiber length led to an increase in tensile strength, young's modulus, and impact strength of kraft fiber reinforced polypropylene composites.

From the above work and discussion, it can be concluded that the mechanical properties of natural FRP composites are affected not only by the interfacial adhesion between the fibers and the matrix but also by the length and aspect ratio of the fibers and their V_f, orientation, and dispersion in the composites. Moreover, fiber dispersion and length are correlated with the mixing number and shear levels in processing".

3. Machinability of Synthetic Fiber/Polymer Composites

The synthetic fiber composites' machining, for example, carbon fiber and glass fiber composites, is the main issue due to their extreme hardness, inert nature, along with re-fractoriness to machinability in terms of material removal rate, thrust force, cutting power, Ra, delamination size, as well as bearing strength utilizing a drilling procedure [2] [3]. Moreover, synthetic fibers' abrasive nature causes poor surface finish along with fast tool wear. Therefore, for machining procedures, the appropriate selection of cutting parameters as well as tools is very essential. Furthermore, the machining parameters' effect for exam-ple V_f (volume fraction), fiber orientation, drill diameter, speed, and feed influence greatly the materials' machinability (see [2] [3] [7]-[14] [17] [18] [63] [67] [76] [86] [87] [88] [89] [102]. In the following parts, the effects of working parameters on the synthetic fiber-based composites' machin-ability are discussed.

3.1. Effect of the Operating Parameters on Thrust Force

Tsao and Hocheng [90] have researched the impact on machining machinability regarding the thrust force of woven GFRE composites with the use of a driller machine from machining parameters (speed, feed along with drill diameter). The cutting conditions were reported to produce higher than expected thrust strength, but no apparent effect was observed when speed was cut.

Khashaba, El-Sonbaty [83] examined the effect, using a drill machine with 2 distinct methods of cemented carbide (K 10) drills of cutting parameters (feed rate and velocity) under a precise cutting pressure on machinability as regards thrust strength of GFRP (Spur & Brad as well as Stub Length). The findings indicate that the thrust forces of two drills were raised with the raising feed rate under the same cutting conditions and that the thrust pressure values of Brad & Spur were lower than the thrust strength box. Ku, Wang [71] have also done similar work, testing a drilling machine with various cutting speeds as well as various feed rates for the same reinforced material. In the case of neat epoxy, the cutting speed from 10m/minute to 45m/minute has noticed a negligible effect on the thrush force. This may be due to heat increases around the edge of the instrument that has demolished the matrix and therefore decreased the resistance force. Nevertheless, there were conflicting outcomes in GFRE composites. With the increase in cutting speed from 5 m/minute to 45 m/minute, the thrust force reduced by 29.4 percent. Moreover, when drill diameter and V_f fiber were increasing, the thrust strength increased by 62.5%. Mata, Gaitonde [14] used a drill press to report similar research, material as well as results. The reactions of the thrust force were delayed, and because of the matrix softening to the generated heat, thrust force values were reduced. Furthermore, the speed reduction effect on thrust force has been noticeable.

To examine drilling variables' effect on machinability using tipped-carbide drilling tool on drilling machine, Jacob, Thomas [82] utilized a high V_f (66%) GFRC (glass/phenolic woven fabric) and several holes (300). Results have shown that the thrust force is rising as the feed rate rises. This could result from an increase in the undeformed chip's cross-section area. A progressive, slow increase of thrust strength with the growing number of drilled trout, usually linked to the steady wear state of the cutting edge, was observed.

El-Sonbaty *et al.* [95] used drilling to study the effect of two forms of the matrix (thermoset and thermoplastics) on machinability in terms of the thrust force of woven GFRC. This has been found that with the rise in drilled holes, thrust forces also rise for both matrices, however, the increase has been greater in the thermoset composites. The cause of this may have been machining-induced defects, for example, delamination and debonding.

Tsao and Chiu [19] inspected the machinability cutting parameters' effects in thrust force using three types of stepping-core drills (saw, twist, as well as a candle) for laminates used for CFRP (carbon-fiber-reinforced plastic) compositions. The used cutting parameters were 800 - 1200 revolutions spindle speeds per minute, 8 - 16 mm/rev feed rates, 5.5 - 7.4 mm/mm diameter ratios. The increased performance parameters were found to lead to an increase in thrust force. By reducing the diameter and spindle speed as well as increasing feed rate, the highest thrust force was achieved.

Instead, when spindle speed along with diameter ratio was increased and feed rate was lower, the lowest thrust has been recorded. In addition, it proposes the highest thrust force in the step-core saw. The main cutting parameters were the diameter ratio (1200 RPM). The reasons for these findings were, however, not obvious. There were two main cutting parameters for example diameter ratio along with feed rate while the best experimental conditions have been found by a combination of 1200 RPM spindle speed, 8 mm/rev low feed rate along with 0.74 mm/mm high diameter ratio. However, the reasons for such outcomes were not clear.

Bras, Hassan [79] evaluated the machining parameters' effect (drill diameter, speed as well as feed) for the machinability of drilling tissue composites utilizing drill machine. By comparing two drills of various diameters, the cutting parameter's effects were investigated on thrust force. For drilling processes, a radial drill machine with carbide cemented drills has been utilized. The outcomes also demonstrated that thrust force raised with a higher cutting rate of feed for each drill diameter. But the drill showed higher thrust forces with a larger diameter. This has been due to an increase in the chip formation resistance along with axial thrust as the cross-sectional area of the undeformed chip has increased.

Tsao and Chiu [19] researched the impact of drilling parameters on the machinability of CFRPs for thrust forces. The parameters investigated have been the spindle velocity for inner diameters (1.088 - 1.360 RPM) and outer spindles (1.000 RPM - 1.214 RPM), the cutting velocity ratio (−2 - 2), 10 - 20 mm/min feed rate, (outer drills and inner drills). Due to the chip clog in the drill head, feed rate, cutting speed, along the type of inner drill had impacts on thrust force. Nevertheless, when compared to the other factors, the stretch, as well as outer drill diameter, had the least impact on thrust force generated by composite. In addition, when a small feed rate has been utilized and smaller chips were produced as well as delamination was reduced.

Eichhorn, Baillie [62] investigate the impact on machinability of thin CFRP laminates by utilizing carbide drill (K20) by drilling parameters (feed rate and spindle speed). This was discovered that feed rate is directly proportional to thrust forces. As a result of the rise in the self-generated feed angle, the drill's working clearance angle was reduced significantly, resulting in the drill rubbing against the work material as well as generating higher thrust forces, which may have contributed to this. On the other hand, it has been discovered that thrust forces decrease as spindle speed is increased. The increasing temperature along with spindle speed may cause the composite to soften, which could explain the phenomenon. A brief discussion on the effect of operating parameters on the machinability of the composites based on synthetic fibers is shown in **Table 2**.

3.2. Effect of the Operating Parameters on Surface Roughness

Hocheng and Tsao [91] investigated the impact on machinability of GFRE composites using a drill machine of machinations by using processing parameters (feeds, speeds, and cutting diameters). Ra has been reported to rise at the cutting feed rate, however, there was no apparent impact of cutting speed. Davim and Reis [4] have studied the impact on machinability of Ra for GFRPs of cutting parameters (feed rate as well as cutting speed) at precise cutting pressures. Two various kinds of cemented carbide (K10) drilling were fitted to the machine (Stub Length and Brad & Spur). For both drills, the findings showed high Ra values. Moreover, the Brad & Spur performance was higher than Stub Length performance drill, which produced small Ra. More values at high feed rate have been observed whereas lower Ra values at high cutting speeds have been obtained, meaning better finish at a high cutting speed along with low feed rate.

Table 2. Effect of the operating parameters on machinability in terms of thrust force.

Researcher	Synthetic fiber	Matrix	Operating parameters	Findings
Tsao and Hocheng [90]	Carbon fiber	Plastic	• Diameter ratio • Feed rate • Spindle speed	• The highest thrust force was by decreasing diameter ratio, spindle speed, and increasing feed rate • Lowest thrust force recorded when diameter ratio and spindle speed increased while decreasing feed rate
Khashaba, El-Sonbaty [93]	Woven Glass fiber	Epoxy	• Feed rate • Spindle speed • Drill diameter	• Increasing the cutting feed rates increased the thrust force • Higher thrust forces were obtained with a bigger diameter.
Tsao and Chiu [19]	Carbon fiber	Plastic	• Spindle speed • Cutting velocity • Feed rate	• Cutting velocity and feed rate have the most impact on thrust force
Krishnaraj, Prabukarthi [96]	Carbon fiber	Plastic	• Spindle speed • Feed rate	• Thrust forces increased with an increase in feed rate • Thrust forces decreased with an increase in spindle speed

Khashaba, El-Sonbaty [83] examined the impacts of cutting parameters (cutting feed as well as speed) on processability in the FRPs with two different matrices of the Brad & Spur cemented carbide (Viapal VUP 9731 and ATLAC 382-05) on specific cutting forces (K10). The outcomes showed that with increased feed rates, Ra increased and decreased with a higher cutting speed.

In their research, El-Sonbaty, Khashaba [95] looked at the effects of 218 - 1850 RPM cutting speed, and 8 - 13 mm drill size, 0.05 - 0.23 mm/rev feed rate on glass fiber reinforced epoxy composites. They were utilizing standard cutting processes to evaluate fiber V_f (0 - 23.7 percent) with Ra machinability. The cutting velocity and feed rate had little influence on Ra for nice epoxy. The composites of GFRE, however, revealed various outcomes. A 75 percent drop in Ra (from 8 microns to 2 microns) was noted with an increased speed, V_f, and driller diameters. This occurred because the reinforcing fibers supported by the matrix were increased. Mata, Gaitonde [14] *et al.* have reported similar studies, material, and findings.

Palanikumar [104] investigated the influence of machining parameters (feed rate, cut depth, fiber orientation, cutting speed) on machinability in terms of Ra for GFRE composites while utilizing a drill machine. In this study, this has been discovered that Ra dropped as cut depth and cutting speed increased. Ra, on the other hand, rose in proportion to the increase in feed rate as well as fiber orientation.

Bras, Hassan [79] examined the machining parameters' effects (drill diameter, speed as well as feed) on machinability in terms of Ra. In this experiment, two drills of various diameters were used for evaluating the cutting parameters' effect on Ra. The drilling procedures have been performed with the help of a radial drill machine and cemented carbide drills. At low cutting feed rates, the findings revealed that a full shearing of the fiber occurred, resulting in a surface finish that was considered to be of reasonable quality. Ra, on the other hand, rose in response to an increase in the cutting feed. This might be because partly sheared fibers have a relatively high Ra. The cutting speed, on the other hand, was not shown to have a significant impact. Furthermore, the cutting speed was discovered to have the most physical impact on Ra for both composite materials, and this has been the cutting parameter with the greatest physical influence on Ra.

Kini and Chincholkar [94] investigated the influence of machining parameters (tool nose radius, cut depth, feed rate, speed) on the machinability of GFRC plastic "in terms of Ra, utilizing a turning lathe equipped with coated tungsten carbide inserts. In their research, they discovered that a low feed rate" (0.25 mm/rev) resulted in greater Ra levels (2.48 m), presumably because the fibers flowed easily at this rate, leading Ra to rise. Similarly, this was also discovered that feed rate was the most critical issue influencing Ra. A brief discussion on the effect of operating parameters on the machinability of the composites based on synthetic fibers is shown in **Table 3**.

Table 3. Effect of the operating parameters on machinability in terms of surface roughness.

Researcher	Synthetic Fiber	Matrix	Operating Parameters	Findings
Hocheng and Tsao [91]	Woven Glass fiber	Epoxy	• Feed rate • Spindle speed • Drill diameter	• Ra increased with an increased cutting feed rate • No obvious effect of cutting speed
Palanikumar [106]	Glass fiber	Epoxy	• cutting speed • Fiber orientation • depth of cut • Feed rate	• Ra decreased as cutting speed and depth of cut increased • Ra increased as feed rate and the fiber orientation increased
Khashaba, El-Sonbaty [93]	Woven Glass fiber	Epoxy	• Feed rate • Spindle speed • Drill diameter	• Ra increased with increasing the cutting feed • no clear effect of cutting speed
Kini and Chincholkar [94]	Glass fiber	Polymer	• Feed rate • Spindle speed • Depth of cut	• Large values of Ra recorded at low feed rates • Feed rate is most effective factor

3.3. Effect of the Operating Parameters on Hole Accuracy

Many studies, for example [8] [9] [93], have investigated fixed dimensions and geometric tolerances. Nevertheless, the nature of the composites produced few useful outcomes. Hole features can contribute to early failure, particularly in the attachment assemblies. There are various methods to describe the quality of the generated hole [9]. The characteristics of workpieces may be characterized as a geometric error or a series of errors. Errors in hole roundness and holed size have been the most critical criterion highlighted by Jain, Choudhury [9]. The fibers were bent throughout the drilling process as well as broken by the effect of the cutting edge. The fibers tried to reset after the shear failure, which caused a strain around a drill and therefore reduced the size of the drilled hole to below the cutting diameter. This is frequently found when composites are drilled laminated GFRP.

Nevertheless, when GFRP composites with a greater fiber content are drilled, such a decrease has not been seen because the woven fabric, according to Khashaba et al, does not enable fibers to bend much [93]. Synthetic polymeric composites are widely machined, particularly by drilling, to produce riveted. The usage of these polymer compounds by traditional drilling techniques is widely known to be challenging to generate with good quality lights [53]. Highly efficient. Therefore, the most precise holes must be created with costly drilling procedures and specific drill bits.

Beg and Pickering [8] performed several drilling tests with high-speed steel (HSS) drills on woven glass fabric/epoxy. The first and last hole exit micrographs varied substantially. This can be seen clearly that the first hole was more accurately drilled than the last one, and the accuracy of the holes declined as the number of drilled holes rose. This was because of the gradual usage of the device and rising thrust force at the hole exit. Brahmakumar, Pavithran [99] observed the same outcomes when multiple CFRP drilling trials utilizing carbide driller were performed.

Eichhorn, Baillie [62] examined the drilling parameters' effects (feed rate and spindle speed) on machinability, as measured by the precision of drilled holes in thin CFRP laminates while utilizing carbide drill (K20). For all drilling settings variations in the size of the holes were found. It was discovered that when cutting feeds were low, but spindle speed was high, larger holes were produced. This may be explained by two things. The accumulated friction heat may have led to an increase in the cutting temperature. Secondly, larger shear pressures might be due to increased resistance to cuts, due to thinner uncut chips.

In their survey, Khashaba, El-Sonbaty [83] used a carbide tip drill cutting tool in a high-V_f (66 percent) GFRC (glass-/phenolic fabric) to examine the drilling variables' effects (cutting speed along with feed) and holes (300) on machinability as far as the size of the drilled holes is concerned. Observations were made on the variation in hole sizes as well as a decrease in the frequency of oversize holes as a result of wear on the drill tip as the number of holes drilled increased. Furthermore, it is possible that the change in hole sizes was caused by the thermal shrinkage of the matrix material as a result of the increased temperature. **Table 4** is shown the most important findings of the effect of operating parameters on the machinability of the composites based on synthetic fibers.

3.4. Effect of the Operating Parameters on Cutting Force Using Drill Machine

Khashaba, El-Sonbaty [83] examined the cutting parameters' effects for drilling (cutting feed as well as speed) on the processability of precise cutting strength in FRPs using a Brad & Spur cemented carbide drill (K10) for two distinct matrices (Viapal V UP 9731 and ATLac 382 05). The findings showed clearly, that as the two cutting parameters dropped, particular cut force (kc) decreased. With the same cutting settings, the Viapal VUP 9731 matrix demonstrated lower kc values (cutting feed and velocity). However, a cutting parameter that had the greatest effect on a particular cutting force has been determined to be feed speed for each composite material.

In terms of specific cutting force as well as force, Davim and Reis [4] have analyzed the interaction impacts of machining parameters (cutting feed as well as speeds) on machinability of plain PEEK (Polyether Ether Ketone) and reinforced PEEK (30% carbon fibers, 30% glass fibers). A lathe was utilized fitted with carbide cemented tools (K10). The findings indicated the inclusion of the reinforcement improvements by 42.8 percent and 15.4 percent respectively, the mechanical characteristics (tensile modulus along with strength). Although the mechanical characteristics of reinforced PEEK have improved, the cutting power and reduction force for all materials increased 90 percent over those of plain PEEK was found as shown in **Table 5**. Consequently, reinforced PEEK machinability is more costly than nice PEEK.

Table 4. Effect of the operating parameters on machinability in terms of hole accuracy.

Researcher	Synthetic Fiber	Matrix	Operating Parameters	Findings
Krishnaraj, Prabukarthi [96]	Carbon fiber	Plastic	• Feed rate • Spindle speed	• Larger hole sizes recorded at lower cutting feeds and high spindle speed
Velayudham, Krishnamurthy [107]	Glass fiber	Polymer	• Feed rate • Spindle speed • Number of drilled holes	• A variation in hole sizes has been noticed • Reduction in oversize has been observed as the number of holes drilled increased

Table 5. Effect of the operating parameters on machinability in terms of cutting force.

Researcher	Synthetic Fiber	Matrix	Operating Parameters	Findings
Davim and Reis [4]	• CF 30% • GF 30%	PEEK	• Cutting speed • Feed rate	• Tensile modulus increased 42.8% • Tensile strength increased 15.4% • Increase in cutting power and cutting force by 90%

3.5. Effect of the Operating Parameters on Delamination Using a Drill Machine

Due to its inherent characteristics, polymeric composites are regarded preferable to be used as structural components [53]. However, composites with low drilling efficiencies and unwanted drilling-induced delamination are seen as challenging to machines [11]. Due to various types of damage, drilling holes are possible. These may be divided into 4 types: delamination, damage related to temperature, geometric defects, delamination at drill entry [72].

Delamination or interlaminar cracking in polymer composite materials is regarded as one of the major types of damage. The major difficulty related to drilling composite fiber-reinforced materials is examined. The Commission is responsible for the refusal of around 60% of aviation industry components [73]. Delamination may be split into two groups: peel-up delamination that happens at the entry along with push-out delamination around the perimeter of the drilled hole, which takes place at the outlet surrounding the drilling hole periphery.

Delamination may lead to decreased material's structural integrity, low assembly tolerance, stiffness, and gradual degradation; it might result in a long-term loss of performance [54]. Delamination generally refers to the layer's separation into the composite through cell migration procedure that may be described further as motion by an external force, such as drilling of certain cells in the composite. The rise in delamination causes the Polymer Composite Structure to become stiffer, degraded, and eventually fail. Several approaches for measuring lamination after drilling composites have been utilized. These photographs are digital [108] [109] [110], S-Can [10], and a microscope shop. a series of GFRP composite twist drilling tests have been performed utilizing traditional drilling and vibration-based twisting for comparison of the delamination created by both procedures [13] [58]. Both approaches found that delamination was observed, although conventional drilling caused more delamination as compared to vibration-assisted drilling. This may be produced by a rise in thrust force when composite laminates are used to conventionally drill.

In terms of the machinery size delamination of the woven GFRE composites Bras, Hassan [79] employing cemented carbide drill, examined the influence of machinery parameters (speeds, feeds along with drill diameters). Delamination-free holes have not been found. Push-out and Peel-up delamination of all machining parameters were evident in the pictures. Increased delamination via an increased feed rate, spindle speed, and drilling diameter. This occurred because the cross-section of the non-deformed chip grew, resulting in a higher thrust strength and a heat build-up near the tool edge, that degraded the strength of the matrix.

Ciftci, Turker [111] have achieved the same results with drills of various kinds (candlestick, twist along with saw drills) with thick carbon FRP. Ultrasonic scanning photos indicated that the delamination took place with all forms of drills, but more delamination was shown by the twist drill than by the saw drill and candlestick. It was because the cutting blades of the drills were different. Similar results have been published [13]; in this work, drilling techniques for hole formation have been employed for short GFC composites using 2 standard high-speed drilling machines.

Harper, Turner [100] investigated the impact of three prepreg types with woven shapes or unidirectional on holes drill (3750) as well as feed rate (0.2 - 0.4 mm/rev) together with the influence on the machinability of CFRP's cutting feed rate at the level of delamination. First, due to the proximity to the net shape manufacturing processes, the CFRP composites require fewer machining operations than the conventional materials. However, in terms of components and integrity, machinability issues were evident. Second, when the feed rate was 0.4 mm/rev, the longest instrument life has been found. Thirdly, usual wear on the drill head was evident in the SEM pictures, and for the majority of the holes drilled at a higher input rate, a catastrophic error was detected. A brief discussion Effect of the operating parameters on machinability in terms of delamination is shown in **Table 6**.

Table 6. Effect of the operating parameters on machinability in terms of delamination.

Researcher	Synthetic Fiber	Matrix	Operating Parameters	Findings
Arul, Vijayaraghavan [112]	Glass fiber	Plastic	• Conventional drilling • Vibration-assisted twist drilling	• Delamination accorded in both techniques • Conventional drilling-induced more delamination
Khashaba, El-Sonbaty [93]	Glass fiber	Epoxy	• Feed rate • Spindle speed • Drill diameter	• Delamination-free holes have not been obtained • Peel-up and push-out delaminations have been obvious • Delamination size increased with increasing feed • Delamination size increased with increasing feed, spindle speed, and drill diameter
Shyha, Soo [20]	Carbon fiber	Polymer	• Number of holes • feed rate	• Difficulties in machinability were presented • The worn lip of the drill head was obvious

4. Machinability Performance of Natural Fiber/Polymer Composites

This was also observed that machinability of these materials was less important than the machinability of Synthetic Materials for Ra, tool wear and life, cutting strengths, mate-rial elimination rate, cutting force, special cutting pressure, and machining force (**Figure 7** and **Figure 8**). The obtained observation stimulated the work under way for studying the machinability of polymer composites based on natural fiber.

4.1. Effect of Treatment on Machinability of Natural Fibers Reinforced Polymeric Composites

The machinability of natural fiber polymer composites' literature can be viewed in the figures mentioned (**Figure 7** and **Figure 8**). Although the following sections examine key findings of works and identify the main problems because of the available resources for the various work procedures for natural fiber polymer composites. Natural fibers were utilized in composites as reinforcements for decades, but their machinability has been limited by their poor adhesion to most polymeric matrices. Due to their hydrophilic nature, natural fibers harm their adhesion to hydrophobic matrixes, which can result in interlocking between matrix and fiber being prevented [54] [81]. The fiber surface should be changed to enhance adhesion as well as, consequently, the composites' machinability [58] [81]. This can be accomplished by modifying the fiber surface.

Mylsamy and Rajendras [20] studied the effect on machinability of fiber-matrix interaction for alkaline treated and untreated fibers by utilizing a frying machine from alkali-treated fibers (5 percent) of short-scale agave fiber-reinforced epoxy composites. The treatment was performed on rough surfaces that resulted in better fiber-matrix interlock and a rise in the contact area. In the untreated fibers, however, a void was observed [45] [50]. To prevent them, a modification of the fiber surface needs to be made in favor of adhesion for enhancing the composites' machinability [58] [81].

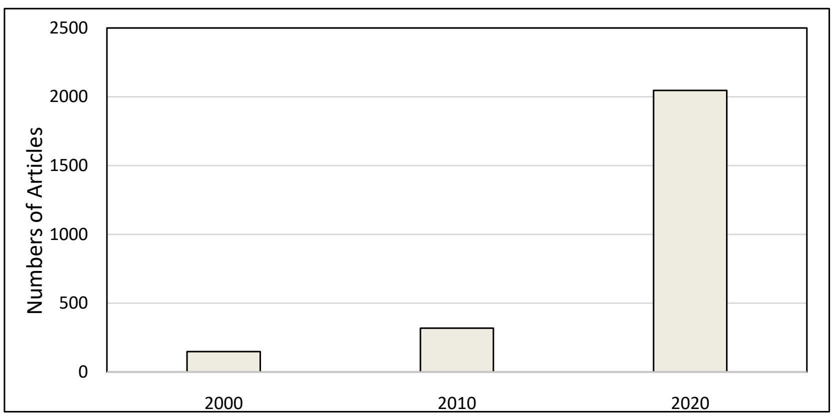

Figure 7. Comparison between the years 2001 and 2011 of the number of articles published on the machining and machinability of polymeric composites based on natural fibers [113].

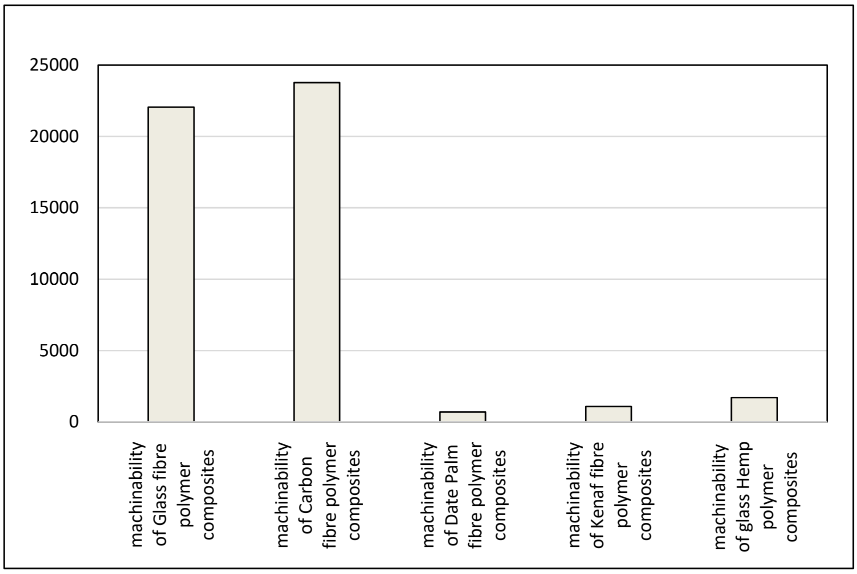

Figure 8. Comparison of the number of articles published on the machinability of polymeric composites based on natural and synthetic fibers (until 2020) [113].

According to Athijayamani, Thiruchitrambalam [55], a drilling process was used for investigating the effects of alkali treatment on machinability of a natural fiber (sisal and roselle) hybrid polyester composite in terms of weight loss. The fibers have been subjected to a 10-percent NaOH solution treatment for varying times (2, 4, 6, and 8 hours). With the rise in wear test time (4, 8, and 12 minutes), Gradual weight loss has also been raised, and the alkali-treated composite samples outperformed the untreated composite samples in terms of wear performance. A possible explanation for this is that the alkali treatment removed moisture from the fibers that resulting in interfacial bonding strength between matrix as well as reinforcement.

In their study, Nam, Ogihara [54] used a drilling process to investigate the machinability of alkali-treated and untreated (5 percent NaOH) "coir fiber-reinforced poly (butylene succinate) biodegradable composites" in terms of the Ra. A 5-percent alkali treatment for 72 hours increased Ra along with cellulose amount exposed on the fiber surface, according to some researchers. This improved the mechanical interlocking between matrix and fiber, as well as the composite material's machinability. A brief discussion on the effect of treatment on machinability of natural fibers reinforced polymeric composites is shown in **Table 7**.

4.2. Effect of Fiber Physical Properties

Few papers have reported the parameters, which impact the natural fiber composites' machinability using a milling machine (*i.e.*, the fiber distribution in the matrix, porosity, moisture absorption, diameter, and length of the fiber, along with how fibers break). Mylsamy and Rajendran [48] studied the impacts of fiber length (3 mm, 7 mm, and 10 mm) on machinability for dimensional accuracy of the drilled holes (4 mm, 6 mm, 8.5 mm, and 12.5 mm) utilizing a drill machine to determine the machinability of various fiber lengths. On short-agave agave fiber-enhanced epoxy composites, an HSS drill bit has been utilized at 260 RPM. The 3 mm fiber-long compound with better dimensional accuracy was found to be optimum from the drilled hole test. As the results show, shorter fibers have improved the mobilization and impregnation of fibers. In turn, this resulted in improved workmanship.

The effects of the fiber content in the drilled-loom dimensional accuracy of a drill machine were investigated by Athijayamani, Thiruchitrambalam [55] for hybrid polyester composites (5, 10, 20, and 30 wt. percent). Composite specimens with a fiber content of 30 wt. percent showed greater precision in their dimensions than composite specimens with a fiber content of 5 wt. percent. This can be due to the increased number of fibers that helped to maintain the surface of the drilled hole. A brief discussion on the Effect of fiber physical properties on machinability of natural fibers reinforced polymeric composites is shown in **Table 8**.

4.3. Effect of Operating Parameters and Conditions

Jayabal, Natarajan [43] studied the impacts on usability of "tool wear for hybrid composites, E Glass and Natural Coir Fiber, utilizing a drill machine", of drilling parameters for example drill bit diameter, feed rates as well as the spindle speed. Feed rate has also been observed to have a more essential purpose than other factors in the instrument wear mechanism because of hole size and the fibers contracted in composites. Between feed rate and drill bit diameter, more effective interaction on machinability was found. The optimal level for achieving a minimum tool wear value (0.2 mm/rv feed rate; 1.503 RPM spindle speed and 8mm diameter) has also been determined.

Table 7. Effect of treatment on machinability of natural fibers reinforced polymeric composites.

Researcher	Natural Fiber	Matrix	Treatment	Findings
Mylsamy and Rajendran [48]	Agave	Epoxy	5% NaOH	• Rough surfaces have been observed • voids have been noticed in the untreated composite
Athijayamani, Thiruchitrambalam [55]	Roselle Sisal	Polyester	10% NaOH	• Gradual weight loss has been observed • alkali-treated composite samples showed superior wear performance
Nam, Ogihara [54]	Coir	butylene succinate	5% NaOH	• increased surface roughness with increasing immersing time

Table 8. Effect of fiber physical properties on machinability of natural fibers reinforced polymeric composites.

Researcher	Natural Fiber	Matrix	Physical Properties	Findings
Mylsamy and Rajendran [48]	Agave	Epoxy	Fiber length (3 mm - 10 mm)	• 3 mm fiber length was found to be optimum • 3 mm showed better dimensional accuracy
Athijayamani, Thiruchitrambalam [55]	Roselle Sisal	Polyester	fiber content (5%, 10%, 20%, and 30%)	• 30 wt% fiber content showed better dimensional accuracy

Jayabal *et al.* [43] studied the drilling parameters' impacts, for example, spindle speed, feed rate, drill bit diameter, on machinability in terms of natural coir fiber, E-glass and tool wear for hybrid composites, utilizing a drill machine. The feed rate was observed to have a more essential purpose than other factors in the tool wear mechanism because of the hole size and the fibers contracted in composites. The negligibility of the impacts on machinability of spindle speed as well as drill bit diameter parameters has been because of composite softness. The most efficient interaction on machinability has been observed to be between feed rate along with drill bit diameter. In addition, the optimum levels for attaining a minimum value have been found for tool wear (0.2 mm/rev feed rate, 1503 RPM spindle speed, 8 mm diameter).

4.4. Effect of Coupling Agents

No works have been reported about the coupling agent's effects on natural fiber/polymer composites' machinability. Nevertheless, few works describe the tribological nature of these materials, as well as surface roughness, which is also considered in described studies. The efficacy of many coupling agents, which are utilized for enhancing the interface between matrix along with fiber, in changing the interface by forming a bond among composite components has drawn considerable attention [40] [53] [58]. For example, vinyl tris (2-methoxy) silane and methacryloxypropyltrimethoxy silane are two coupling agents that were utilized in current research for changing the surface of fibers properties. The fiber's compatibility with the utilization of polymeric matrix may also be enhanced using these coupling agents [46] [101] [103].

Demir, Atikler [53] analyzed the impacts of silane coupling agents for polypropylene-luffa fiber, specifically AS am (inopropyltriethoxy silane) and MS (mercapto silane), on machinability as measured by Ra. A silane layer was used to raise the coverage of the fiber surfaces, which resulted in lower Ra values (88 nm and 85 nm, respectively) than untreated composite (138 nm). This was due to the increased coverage of the fiber surfaces by the silane layer.

5. Conclusions and Future Perspective

Machinability and mechanical properties of natural fiber-reinforced composites were reviewed according to many parameters such as chemical treatment, fiber orientation, volume fraction of fiber, physical properties of fibers and operating parameters. The main findings of this research are concluded in the following points:

1) NaOH concentration influences the strength of the fibers significantly, as well as the interfacial adhesion of the fiber with the matrix. This has been found that by removing surface tissues, decreasing moisture absorption as well as rising the *Ra,* the natural fibers' chemical treatment enhanced their matrix compatibility. This also improved the composites' mechanical properties. The length of time chosen for the chemical treatment has been a crucial consideration. The mechani-

cal properties raised when the treatment continued longer but having risen to maximum, they would then fall. Mostly NaOH chemical has been utilized at various concentrations.

2) For controlling the composites' mechanical properties, fiber Orientation has an essential role to play. For controlling the composites' mechanical properties, fiber Orientation has an essential role to play. It was noticed in separate experiments that longitudinal fiber orientation gives more flexural strengths as well as higher tensile than its counterpart with transverse orientation.

3) According to several studies, increasing fiber V_f can improve mechanical properties as well as other properties. Fiber clotting, on the other hand, occurs when V_f exceeds a certain level; as a result, the applied loads cannot be distributed properly, resulting in poorer mechanical properties. Thus, to strengthen the composite the fiber V_f value must be optimized.

4) According to the findings, certain fibers' physical properties such as fiber's quality distributed in the matrix; diameter, length as well as the size of fiber; porosity; "moisture absorption; and how fibers break throughout compounding with the matrix all have an effect" on the composites' mechanical properties. Furthermore, fiber's aspect ratio (L/D) has an impact on the composite material's mechanical properties. Findings also have revealed that decreasing the length of Kraft fiber-reinforced polypropylene composites resulted in increases in impact strength, tensile strength along with Young's modulus.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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