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Machining and characterization of self-reinforced polymers

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Abstract: This Paper focuses on obtaining the mechanical properties and the effect of the different machining techniques on self-reinforced composites sample and to derive the best machining method with remarkable properties. Each sample was tested by the Tensile and Flexural tests, fabricated using hot compaction test and those loads were calculated. These composites are machined using conventional methods because of lack of advanced machinery in most of the industries. The advanced non-conventional methods like Abrasive water jet machining were used. These machining techniques are used to get the better output for the composite materials with good mechanical properties compared to conventional methods. But the use of non-conventional methods causes the changes in the work piece, tool properties and more economical compared to the conventional methods. Finding out the best method ideal for the designing of these Self Reinforced Composites with and without defects and the use of Scanning Electron Microscope (SEM) analysis for the comparing the microstructure of the PP and PE samples concludes our process.

1. Introduction

Composite is a structure or entity made up of two distinct components (or phases) with significantly different mechanical properties and which remains separate and distinct, the resultant final material has properties better than those of individual constituents. Reinforcing phase is in the form of fibres, sheets or particles and is enclosed by called matrix phase, which is continuous in nature, usually more ductile and holds the dissipated phase and shares the load. Composite materials are anisotropic in nature. i.e., its properties changes with direction or depend on the orientation of the fibre particles [1]. Based on type of material used for matrix phase, composites are classified into: PMC, MMC, CMC, [2] Self-reinforced polymers (SRP), Glass-fibre reinforced plastic and Carbon fibre reinforced plastic. Benefits of composites include Light weight, Proper weight distribution, High strength-to-weight ratio [3] Directional strength/stiffness, Corrosion resistance, Resistance to surroundings, Surface finish, Low thermal conductivity, Low thermal coefficient of expansions, High dielectric strength, non-magnetic. These differ from other materials as they have High specific strength, Great fatigue endurance especially for aramid and carbon reinforced epoxies [4], compared with metals and can be made into required shape and size easily.

1.1. Conventional Cutting

A powered saw is a tool used for cutting designs into a piece of wood, metal, or other material. It can be used in a more creative fashion of straight paths [5], which is identical to that of rasp and the chisel. Despite a powered saw can be used to design arbitrary patterns [6], processing a straight cut is tougher. Modern saws are potential tools, compound of a dynamic motor and a reciprocating blade.

1.2. Abrasive Water Jet Cutting

A water jet cutter as shown in Figure1 is an advanced tool used for efficient cutting of wide variation of advanced materials, using a high-pressure water jet and an abrasive substance. To cut hard materials such as granite abrasive particles along with water is used and only pure water jet [7] without the addition of abrasives [8] is used for softer materials like rubber.

Figure 1. Abrasive water jet arrangement

1.3. Scanning Electron Microscope

SEM uses high-energy electrons in focus beam in order to generate vrious signals. The signals interaction with specimen surface predicts surface topography, interface composition, and grain structure and direction of materials. Depending on the data requirent and state of sample SEM analysis is performed as shown in figure 2 . sample dimensioning depends on slot size of SEM in order to aviod electrical insulation. SEM analysis is performed by the generation of X-rays which avoids volume loss of the specimen.

1.

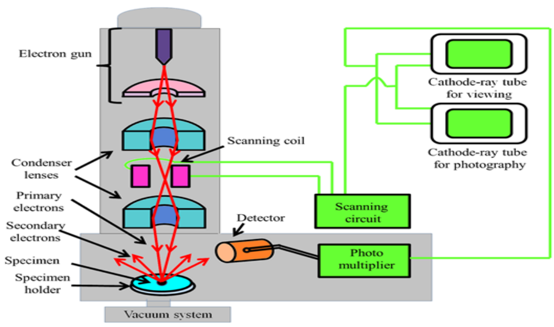

Figure 2. SEM Architechture

2. Literature Review

R. Teti explains about the basic introduction to composites and their classifications like PMC, MMC, CMC [1] composites and problems faced during their machining and the influence of various cutting tools in their machining and the different tool wear mechanisms arises during machining of each type which depends on fibre orientation and volume fraction of both matrix and reinforcement phases, these two strongly determine the strength and mechanical properties of composites. The problems are mainly due to their non-homogeneity and orientation of fibres this results in the proper care taken during the selection of tool geometry and abrasion resistance of the cutting tool .L. M. Morgan etl studied about the SRPC and aimed at arriving the efficient [4] and effective advanced manufacturing process including the peak mechanical properties a material can aquire. After analysing all the processes involved in the formation of SRPC's the best method selected for fabrication is hot compaction method. Hot Compaction method is used to heat polymer tapesto high accuracy. Utilization of pressure makes softened polymer move into mesh to frame a continuous matrix,cooled under pressure to get solidified matrix. Processing of FRP without causing any damage to fibre is quite challenging when processed with conventional processes due to its non homoginity and thermal Unstabilitty.

3. Experimentation Components

3.1 Fabrication

The fabrication method used for SRP's is hot compaction method in which the Commercially available polyethylene and polypropylene sheet and fibre material are taken and cut in to required dimensions i.e. 500mm x 500mm. Sandwiching is done layer by layer as follow

Stacking sequence: **1 PES-3PEF-1PES** (For polyethylene)
1 PPS-3PPF-1PPS (For polypropylene)
Where, PES- Polyethylene sheet (matrix)
PEF-Polyethylene fibre (reinforcement)
PPF-Polypropylene fibre (reinforcement)
PPS-Polypropylene sheet (matrix)

The top and bottom surfaces of the sandwiched arrangement is covered with nylon fabric and sprayed with a non-sticky silicon sprayer, to avoid the surfaces sticking to the mild steel plates. The whole sandwiched arrangement is placed between two thick iron plates to its full tight for compression to create between the layers. This is depicted in the figure shown below (Figure3).

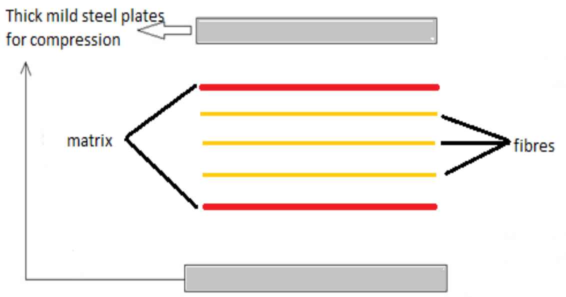

Figure 3. Stacking sequence of fibre and matrix

The whole arrangement is now kept inside the electric oven and heated till 155°c and waited for one hour exactly, and then the setup is allowed to cool for 16-18 hours. Later it is taken out, the nylon sheet, iron sheets and clamps were removed and the material is taken out. .

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The edges are machined for proper dimensions and to achieve even composition of matrix and fibre edges. The final fabricated composite sheet is shown in figure below. The thickness of the material is around 1.9 and is measured using Vernier callipers. The specimens are machined using conventional and unconventional machining methods. Unconventional method involve abrasive water jet cutting.

IOP Conf. Series: Materials Science and Engineering **263** (2017) 062044 doi:10.1088/1757-899X/263/6/062044

Specimens were machined according to ASTM standards and Tensile, flexural tests were done and mechanical properties are obtained for both Polyethylene and polypropylene. Characterisation techniques were done on the specimens to determine the microstructure of the samples machined using different methods and fibres orientations in each case were analysed.

3.2. Testing Methods Used

- *Tensile Test*

INSTRON 8801 is used for both dynamic and static loading requirements. The specimen is loaded axially (shown in Figure 4.) and load is applied readings are obtained in the monitor and readings are tabulated

The single set up can be used to perform multiple tests like tensile, flexural, fracture and fatigue. The main features of INSTRON 8801 are as follows

- Capacity of ±100 KN.
- Inertial loads compensated by Dynacell load cell.
- Wide range of grips, fixtures, accessories and extra height frame.

Figure 4. Tensile failure point

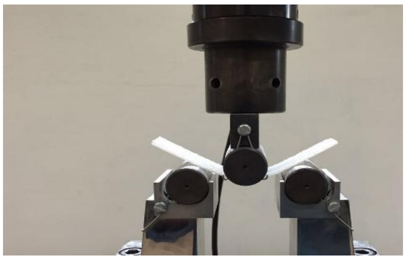

Figure 5. Flexural failure point

- *Flexural Test*

Three point bending test is done to determine the flexural properties of the material and is supported on two ends and at the middle of the span length a load is applied and load is applied till it breaks as shown in Figure5.

4. Codes and Standards

In order to perform tests using UTM a specimen to be loaded, the specimen dimensions are dependent on the type of test and the dimensions are varied with change in parameters. So, if one intends to perform these tests, the following standards shown in Table 1 are to be followed to determine the specimen dimensions.

Table 1. Codes and standards for specimen.

S.no	Type of test	Standard &code	Specimen dimensions (mm)	Parameter obtained
1.	Tensile test	ASTM D3039	Length=250, width=25 Thickness (up to)=2	Tensile strength
2.	Bending test	ASTM D790	Length=125, width=25 Thickness=2	Flexural strength
3.	Hot ground plate test	ASTM E1530	Dia. = 10, thickness (up to= 3	Thermal conductivity

5. Results and Discussion

The specimens are machined using conventional and unconventional machining methods according to ASTM standards. Unconventional method involve abrasive water jet cutting. Tensile, flexural tests were done and mechanical properties are obtained for both Polyethylene and polypropylene. Characterisation techniques were carried out on the specimens to determine the microstructure of the samples machined using different methods in each case was analysed.

5.1 Results of Polyethylene and Polypropylene

Table 2. Tensile test results for PE and PP conventional samples

Polymer	Type Of Machining	Maximum Tensile Load(N)		Ultimate Tensile Stress (Mpa)	
		with defects	without defects	with defects	without defects
P.E	AWJ	1612.96	1617.8	27.667	31.667
	conventional	893.606	1457.922	14.5	28.333
P.P	AWJ	2108.9	1605.707	34.333	29.5
	conventional	1168.087	1196.4	18	22.33

The results shown in Table 2 depict that a P.E sample with defects is advised to be cut using the AWJ method as it gives almost double the strength than that of conventionally cut sample. And also for a P.E sample without defects AWJ is a better choice. When it comes to the case of P.P sample, AWJ cutting method is preferable for both the samples with and without defects.

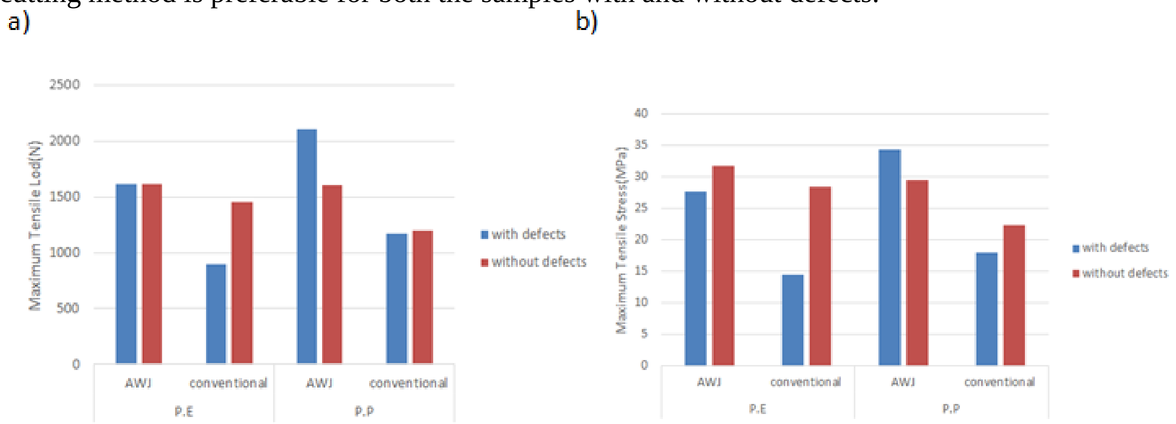

Figure 6. a) Maximum tensile load; b) Maximum Tensile stress for P.E and P.P samples with and without defects

But in the case of PE sample with defects as the difference in stress values between the conventionally cut sample and the AWJ cut sample which is almost negotiated under normal usage. Hence either of the ways can be used to cut a P.E sample without defects. In PP sample with and without defects there is a significant difference in the load and stress values of AWJ cut sample and conventionally cut sample as shown in Figure 6. Hence the way the sample is cut influences the strength and hence its usage.

Table 3. Flexural test results for PE and PP conventional samples

Polymer	Type Of Machining	Flexural Load(N)		Flexural Stress(Mpa)	
		with defects	without defects	with defects	without defects
P.E	AWJ	18.95	38.806	29.796	34.528
	conventional	17.411	41.956	27.74	40.064
P.P	AWJ	23.586	45.774	30.53	35.143
	conventional	22.572	50.393	28.43	39

The flexural test results shown in Table 3 explain us that for a P.E sample with defects, AWJ method of cutting is preferred to the conventional method. And for a P.E sample without defects conventional method of cutting is preferred. And same is the case for a P.P sample with and without defects. A sample with defect is preferred to be cut by AWJ method and a sample without defect is preferred to be cut by conventional method.

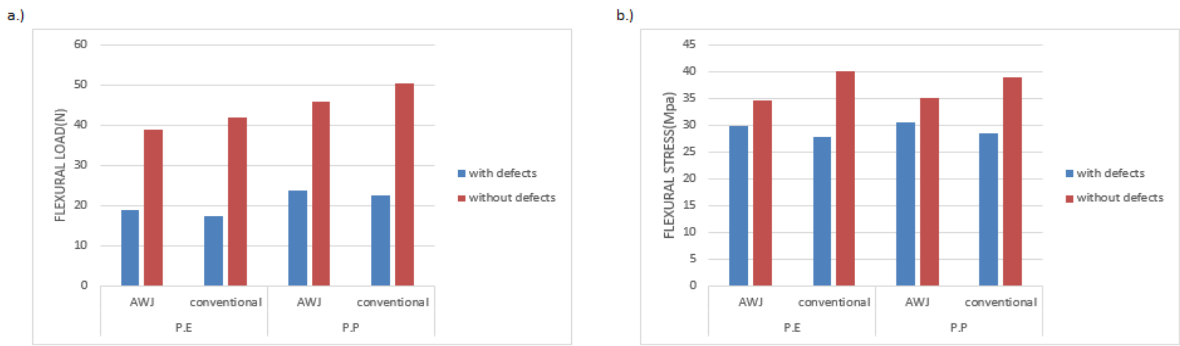

Figure 7. (a) Flexural Load; (b) Flexural stress for P.E and P.P samples with and without defects

However there has not been any noticeable difference in between the flexural stress values for both the PE samples as shown in Figure 7. Hence other parameters like usage, cost, etc. can be give priorities over the method of cutting as both the methods give almost the same strengths to the sample. Similarly the difference is negligible as in the case of P.E sample. Hence the method of cutting barely influences the strengths and the uses of the sample.

5.2 Scanning Electron Microscope Images

The microstructure changes and the fibre orientation of the composite were studied using SEM and a two dimensional image is taken at a suitable magnification.

a) b)

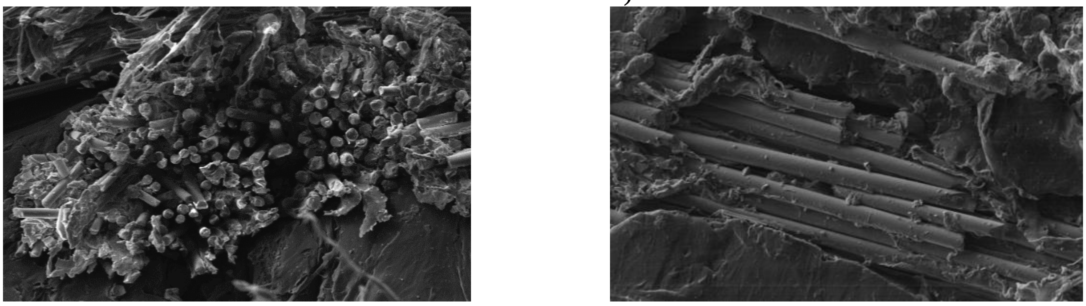

Figure 8. SEM image of PE (a) AWJM sample; (b) Conventional sample.

The SEM image for both AWJM cut sample and conventional cut sample were taken and is noted that the fibres are cut more precisely in case of Abrasive water jet when compared to conventional cutting. Surface finish is also smoother than conventionally cut sample(Figure 8).

a) b)

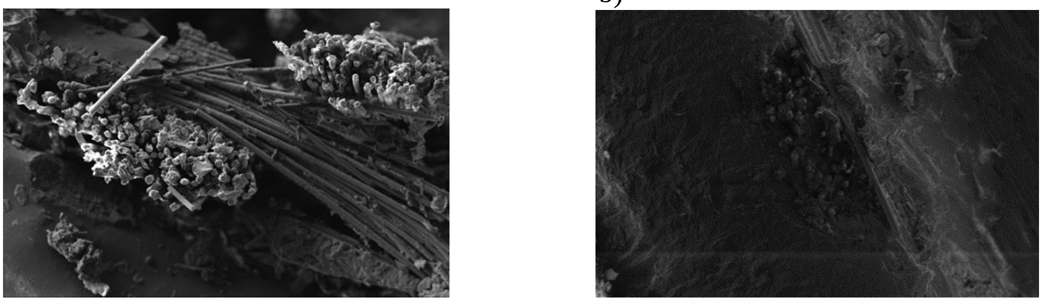

Figure 9. SEM image of PP (a) AWJM sample; (b) conventional sample

The Abrasive water jet cut Polypropylene sample and conventionally cut Polypropylene sample images are taken at an observable magnification (Figure 9) and is noted that fibres placing are more accurate and undisturbed in case of water jet cutting and whereas in case of conventionally cut sample using conventional saw the fibres are disturbed and not evenly cut which results in poor surfaced finish and in some cases fibres pull out also observed.

6. Conclusion

The fabricated sheet is cut into samples according to the ASTM standards on which different machining methods like conventional and un-conventional methods were done. It is noted that the flexural test results are almost the same for both the samples whether it may be a defective sample or a sample without defect. Hence it is not evident that we cannot distinguish the cutting methods based on flexural test results. Hence we need to take tensile test results and the SEM results into consideration for finding out the best method of cutting. Hence we can observe that Abrasive Water Jet cutting happens to be the most promising cutting method as there is a noticeable difference seen in the strengths of the samples when cut with AWJ. According to the results obtained from our experimentation, the strength happens to be around twice that of the strength that we obtain from conventional cutting. Hence AWJ has been decided as the best method for cutting either a PP or a PE sample.

Moreover the results from SEM experiment also give evident reasons to say why AWJ is the preferred way to cut the sample because it is clear that the precision and the smoothness of the fibres after cutting is way more better in the case of AWJ cutting than conventional cutting. And the orientation of the fibres in the sample is also undisturbed in the case of AWJ. This is because of the change in chemical composition of the sample material which is a result of the temperature created during the cutting process. Hence through this research we can conclude that Abrasive Water Jet cutting method is the preferred method to use to cut a sample as it produces a higher quality of material after the cutting process than that of produced by conventional cutting method.

7. Acknowledgements

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