DEVELOPMENT OF FUTURISTIC COMPOSITES AND STUDIES ON ITS MACHINABILITY

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by

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Conclusion and Future Work

7.1 Summary of the present work

❖ Ordinary composite Vs Nanocomposite

❖ Tensile Properties

- The mechanical behaviour of zero degree hybrid composites $[HC]_0$ is best among the composites examined having a tensile strength of 164.18 MPa.

- $[HC]_A$'s tensile strength has been reduced by 33% to 109.94 MPa because of the effect of orientation of fibers which is affecting load sharing capacity of fibers and another reason is due to inadequate interfacial bond among the fillers in matrix.

- The strength of nanocomposites was also reduced as a result of the fillers' different molecular weights.

- Tensile properties of nanocomposites were noticeably degraded by the presence of nanofillers. Tensile data of the material have been reduced to 113.97 MPa this is a 31% reduction in strength compared to $[HC]_0$.

- When comparing the promotion of strength employing fillers, nanofillers contribute a decrease in strength.

- Nanocomposites have shown a small change in strength of 31% when compared to $[HC]_0$. Nanoadditives results in reduction of strength of composites. They also encouraged the agglomeration of nanoparticles in resin-free flow areas.

- $[HC]_A$ hybrid composites have a percentage elongation of 3.85. Brittle nature and reduction in elasticity results in a decrease in ductility [28]. The influence of orientation improves composite ductility. It is 3.85 out of 3.71 for hybrid composites.

- Nanofillers reduced the ductility even further. This might be the result of stress concentration and agglomeration at matrix and fiber interfaces as a result, adding nanofillers to nanocomposites reduces their ductility. It is 3.17 out of 3.85 for hybrid composites.

❖ Impact Properties

- $[HC]_A$ having least energy absorption capacity, $[NHC]_0$ having 3.04% more and $[HC]_0$ having highest energy absorption capacity composite in case of U-notch. The inclusion of graphene minimized energy absorption capacity by 7.25% in case of U-notch it is because of the presence of nanofillers and the effect of stress concentration.

- Where as in case of V-notch $[HC]_0$ having least energy absorption capacity, $[HC]_A$ having 3.23% more and $[NHC]_0$ is the highest energy absorption capacity composite. The inclusion of graphene maximized the energy absorption capacity by 10.27% in case of V-notch, here notch help in nullifying the effect of stress concentration which results in improvement in energy absorption capacity.

- In case of Key hole-notch $[HC]_A$ having least energy absorption capacity, $[NHC]_0$ having 13.57% more and $[HC]_0$ having is the highest energy absorption capacity. The inclusion of graphene minimized energy absorption capacity by 7.77%.

- In case of notch free specimen, $[HC]_0$ having least energy absorption capacity, $[NHC]_0$ having 14.38% more and $[HC]_A$ having highest energy absorption capacity composite. The inclusion of graphene maximized the energy absorption capacity by 14.38%.

❖ Wear behavior (Dry)

- The effects of operating parameters on the friction and wear behaviors of composites were remarkable. The friction and wear behaviors of composites varied with operating conditions.

- The wear loss increases with increasing load in case of angle hybrid and GFRP composite where as in case of zero hybrid composite first decreases and than increases.

- The wear loss is maximum in case of GFRP composite followed by angle hybrid composite and least value in case of zero hybrid composite.

❖ Machining characteristics w.r.t. MRR

- Taguchi and regression analysis were carried out to assess the material removal rate (mrr). Analysis of variance (ANOVA) was applied to understand the significance of input parameters and their contribution toward achieving maximum mrr.

- Material removal rate is primarily affected by feed rate (81.81%) and trail by spindle speed (8.37%), wt.% of Graphene (1%) significant.

- The optimal condition for the highest mrr was found to be F3/M2/S1 (feed of 30, Material of angle hybrid composite and tool speed of 1220 rpm).

- The calculated value of mrr (5.5178 mg/min) at the optimum level of input parameters was found to be close to the experimental mrr (6.5068 mg/min). The percentage error between the experimental and calculated value of mrr at the optimum level is very low as 15%.

- This indicates that the developed statistical model is quite significant in predicting mrr during Micro-machining of Nanocomposites.
- The mrr is heavily influenced by the feed rate, tool speed is relatively important, while material is the least important factor.
- It can also be deduced from the graph that the mrr increases as the feed rate increases, owing to the fact that as the feed rate increases, the cutting force increases as well.
- This effect is higher at lower speed and as the speed increases this effect is going to decrease.

❖ 3D printed composite

❖ Tensile Properties

- Material removal rate is primarily affected by feed rate (97.81%) and trail by spindle speed (0.72%), wt.% of Graphene (1%) significant.
- The optimal condition for the highest mrr was found to be F3/M3/S3 (feed of 5, Material of nano hybrid composite and tool speed of 1490 rpm).
- The calculated value of mrr (49.6228 mg/min) at the optimum level of input parameters was found to be close to the experimental mrr (51 mg/min). The percentage error between the experimental and calculated value of mrr at the optimum level is very low as 2.7 %.

- This indicates that the developed statistical model is quite significant in predicting mrr during Micro-machining of Nanocomposites.
- The mrr is heavily influenced by the feed rate, tool speed is relatively important, while material is the least important factor.
- It can also be deduced from the graph that the mrr increases as the feed rate increases, owing to the fact that as the feed rate increases, the cutting force increases as well.
- This effect is higher at lower speed and as the speed increases this effect is going to decrease.

❖ Impact Properties

The effect of filling pattern and reinforcements on the mechanical properties of 3D printed parts in fused deposition modeling (FDM) method:

- Kevlar polymer composite resulted in the highest tensile strengths of 123.48 MPa.
- High strength high temperature polymer composite tensile strength has been reduced by 14.66% compared with glass fiber polymer composite.
- Glass fiber polymer composite having concentric zero degree filling pattern resulted in highest flexural strength of 86.22 Mpa while Kevlar composite showing the lowest value of 45.64 MPa.
- Concentric 90^0 infill pattern giving the highest value of flexural strength compared with zero degree infill pattern.
- HSHT concentric infill pattern giving the highest value deflection.

- GF concentric zero having highest stiffness.

❖ Machining characteristics w.r.t. MRR

- Material removal rate is primarily affected by feed rate (56.90%) and trail by spindle speed (30.40%), significant.
- The optimal condition for the highest mrr was found to be F3/M3/S3 (feed of 30, Material of Glass Fiber composite and tool speed of 1490 rpm).
- The calculated value of mrr (7.1776 mg/min) at the optimum level of input parameters was found to be close to the experimental mrr (6.9120 mg/min). The percentage error between the experimental and calculated value of mrr at the optimum level is very low as 3.7%.
- This indicates that the developed statistical model is quite significant in predicting mrr during Micro-machining of Nanocomposites.
- The mrr is heavily influenced by the feed rate, tool speed is relatively important, while material is the least important factor.
- It can also be deduced from the graph that the mrr increases as the feed rate increases, owing to the fact that as the feed rate increases, the cutting force increases as well.
- This effect is higher at lower speed and as the speed increases this effect is going to decrease.

❖ Ordinary composite Vs Nanocomposite

- Material removal rate is primarily affected by feed rate (57.43%) and trail by spindle speed (14.16%), wt.% of Graphene (1%) significant.
- The optimal condition for the highest mrr was found to be F3/M3/S1 (feed of 5, Material of GF composite and tool speed of 1220 rpm).
- The calculated value of mrr (40.916 mg/min) at the optimum level of input parameters was found to be close to the experimental mrr (55.7 mg/min). The percentage error between the experimental and calculated value of mrr at the optimum level is very low as 26.54 %.
- This indicates that the developed statistical model is quite significant in predicting mrr during Micro-machining of Nanocomposites.
- The mrr is heavily influenced by the feed rate, tool speed is relatively important, while material is the least important factor.
- It can also be deduced from the graph that the mrr increases as the feed rate increases, owing to the fact that as the feed rate increases, the cutting force increases as well.
- This effect is higher at lower speed and as the speed increases this effect is going to decrease.

❖ 3D printed composite

- The mechanical behaviour of zero degree hybrid composites is best among the composites examined having a tensile strength of 164.18 MPa.

- Tensile properties of nanocomposites were noticeably degraded by the presence of nanofillers. Tensile data of the material have been reduced to 113.97 MPa this is a 31% reduction in strength compared to $[HC]_0$.
- The inclusion of graphene maximized the energy absorption capacity by 10.27% in case of V-notch.
- In case of notch free specimen, zero degree hybrid composites having least energy absorption capacity, nanocomposites having 14.38% more and angle hybrid composites having highest energy absorption capacity. The inclusion of graphene maximized the energy absorption capacity by 14.38%.
- The calculated value of mrr (5.5178 mg/min) at the optimum level of input parameters was found to be close to the experimental mrr (6.5068 mg/min). The percentage error between the experimental and calculated value of mrr at the optimum level is very low as 15%.
- This indicates that the developed statistical model is quite significant in predicting mrr during Micro-machining of Nanocomposites which is fabricated by hand layup process.
- The calculated value of mrr (7.1776 mg/min) at the optimum level of input parameters was found to be close to the experimental mrr (6.9120 mg/min). The percentage error between the experimental and calculated value of mrr at the optimum level is very low as 3.7%.

- This indicates that the developed statistical model is highly significant in predicting mrr during machining of ordinary composites which is fabricated by additive manufacturing.

- Effect of nanoadditives: there is a localised stress concentration on the material surface. Furthermore, fiber-matrix interface failure (adhesive fracture) has been seen because of the tensile stress concentration in the fiber-matrix interface.

- The surface shows agglomeration of fillers as well as matrix deformation. The stress concentration zone was formed by overlapping the hybrid fibers.

- The failure of composites is mostly caused by fiber breakage, brittle character of composite and agglomeration of fillers according to the morphological analysis of nanocomposites.

- Fiber pull-out impressions are more prevalent than fracture impressions. Furthermore, the impact has significantly distorted the matrix and fibers as seen in the figure 17.

7.2 Future Work

On the basis of the review, many issues might be identified for potential future study areas:

1. It is interesting to see how nanofillers affect the way the matrix crystallises and how the properties of the interface and matrix are improved. Future research should focus on the mechanical and dielectric characteristics of these interfacial regions in order to better understand the properties of composite materials and to provide data for modelling studies.
2. Many different sectors, including the biomedical, aviation, oil and gas supply, defence, aircraft, electronic, telecommunications, and packaging materials, employ these composites extensively. For many of these purposes, microscale machining of the composite is necessary for shaping and generating the necessary features, as well as for the assembly of various components and many other tasks. To improve the machinability of polymer composites, the researcher's key goal is to determine the ideal level of reinforcement in the polymer matrix.
3. The polymer-filler interface is crucial for the formation of polymer-based composites. The surface chemistry of the contact area needs to be better understood. Some of the topics on which scientists are concentrating include the impact of filler material arrangements, the orientation of the fibre, and their interaction with polymer composite qualities.
4. The process of bonding between matrix-reinforcement and the impact of nanofiller reinforcement in polymer matrix composites must be thoroughly understood.
5. The majority of research in micro drilling has concentrated on machinability analysis, cutting force measurement, chip morphology, delamination analysis, and size effect.

Due to the high cutting force, there is little study on the examination of tool wear and failure. It was found that the majority of the work had only been done on CFRP and GFRP-based composites. The literature on micro drilling of polymers based on thermoplastic and thermoset materials is quite scarce. Studying the impact of lubrication on tool life and surface quality is necessary.

6. Future research can concentrate on different composite combinations, increased tool life, optimum process parameters, hole features, investigation of energy consumption and heat influence zones, and modelling of these phenomena.
7. The majority of the micro milling literature concentrated on machinability studies, size effect, chip morphology, process parameter investigations, and process modelling. Analysis of temperature, condition monitoring, varied lubricating effects of coated and non-coated tools, and profile development have all received very little research attention. The majority of polymers have been investigated are amorphous, such as PC, PMMA, PS, and PVC, but only a small amount of study has been done on semicrystalline polymers, such as HDPE, LDPE, PP, PEEK, poly aryl ether ketone (PAEK), etc. The creation of complicated geometric profiles, the manufacture of microfeatures on different polymers, and improving the micromilling process capabilities might be the main areas of future study.
8. In micromachining, it is necessary to investigate how the filler material is oriented in relation to the cutting direction. Only a small number of scientists have studied machining linked to filler orientation.
9. In order to fully explore the opportunities offered by the various compound families, a variety of 2D materials should be investigated. Only a few MXenes have been studied for use in tribology applications for nanocomposites, despite the discovery of

more than 30 different chemicals. For instance, nitride-MXenes have not, to the best of our knowledge, been assessed for tribological applications despite having superior mechanical characteristics than carbide ones [214,215], which may be advantageous for wear resistance. For nanocomposites that are filled with TMDs, a similar pattern is seen. So, it might be wise to look at different substances. The potential synergistic impact of mixing several nano-fillers is another issue that requires more research. We've mentioned a few papers that deal with this strategy, but more thorough research is required because the data is still rare. It is important to note that an in-depth analysis of mixing reinforcements is exceedingly complicated because to the numerous factors involved and the lack of understanding about the intricate connections between the various fillers and the matrix.