Experimental study on the effect of Nano SiO$_2$ on the Milled GFRP Composite and under Buckling Load

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Abstract

In this study, the effect of Nano silica (SiO$_2$) on the buckling strength of the glass fiber reinforced laminates containing machining process causes holes were investigated. The tests have been applied on two status milled and non-milled. To promote the mechanical behavior of the fiber reinforced glass epoxy base composites, Nano sio2 were added to matrix in order to improve and gradation. Nano sio2 have been chosen due to its flexibility and high mechanical features, also effect of Nano particles on surface serenity have been studied. Thus effect of Nano particles on crack growth and well machining process and delamination caused by machining have been studied. We can also imply that many machining factors are important such as feed rate, thrust force, spindle speed, also feed rate and spindle speed were studied in constant values. That the thrust forces were studied as main factor caused residual stress. And also entrance forces were measured by local calibrated load cell on machining devices. The results showed that the buckling load of milled laminates have been increased about 50% with adding 2 wt% of silica in compare with the neat damaged laminates also adding more contents caused negative effects. Also the comparing two tools, cylindrical radius end tool had less destructive effects on specimens.

1. Introduction

Fiber reinforced epoxy composite industry is facing a significance growth. They are great replacement of those used in building, sporting equipment, home appliances, automotive/ aircraft parts, boat and canoe hull, bodies in recreational equipment and vehicle $^{1,2}$. It also offers many benefits over traditional materials that important of these are high strength, low weight, flexible in design, high dimensional stability, parts consolidation, low tooling cost, and low corrosion $^{3,4}$. Epoxy resins have been used as matrix in composite materials and are a type of polymer. These polymers have been widely used because of their high mechanical and chemical properties such as high strength and high temperature resistance, but epoxy resins have a brittle nature that cause to fracture in low load bearing or impact. So, it is necessary to cope with this problem in epoxy based composites. Due to the tremendous strength-to-weight properties and impressive design flexibility, fiber glass usage has been famed. In the aerospace and high sporting goods utilize premium carbon fiber reinforcement in epoxy.

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matrix because of its high strength and lightweight due to its electrical insulting properties, glass fiber widely has been applied in appliances, tool and other machinery. In addition, corrosion resistant of glass fiber reinforced tank and pipes offer extended life service over metals. Hence, in recent years many of researchers have been focused on to use Nano particles to enhance the mechanical properties of composites. In these composite materials, nano particles are added to matrices as nano fillers and distribute at whole of the matrix in order to make a strong matrix and new composite with high mechanical and chemical properties. The most used nano materials includes of nano SiO$_2$ (Silica), clay, CNT and TiO$_2$. Each of the nano particles have specific chemical and physical properties that could have different effects on composites. Azadi and Rostamiyan applied CNT and clay in order to increase the critical buckling load in hybrid carbon fiber reinforced laminates. The results showed that adding nano clay and cnt with 1 and 1.5 wt% respectively increased the buckling force of laminates about 45%. Choi et al. used MWCNT into polycarbonates composite to investigate the electrical and rheological percolation thresholds of PC/CNT nanocomposites and the results showed a significant and well changes in nano composite.

The manufacturing of the fiber reinforced epoxy composites widely have classified as primary and secondary manufacturing. The primary manufacturing results in near-net shape of the final lay, protrusion, pultrusion, filament winding, vacuum bag molding and resin transfer molding, also can be implied that most composite products are made in near-net shape, certain complexity in the product design necessitate the development of the composite products in parts. Finally, independent manufactured parts are assembled to get the final composite products, thus machining becomes imperative to ascertain the structural integrity of complex composite products. Hole making and milling are the important issues in to machining process due to facilitate the assembly operations.

Though number of approaches have been applied in order to making thorn seat and etc. making hole, conventional drilling and milling till date is broadly acceptable and frequently used on composite laminates machining. Conventional milling results in damage form of delamination, micro cracks, fiber pull out and matrix burning around the hole and thorn seat may ultimately cause variation in the residual strength of the components with milled hole and thorn seat. Thus the milling process delamination and residual strength caused by thrust forces that can be various in hole and thorn depth. The damage generated by thrust force (milling and drilling) during milling of composite products. Thus The damage generated during the milling of composites can be detrimental to the mechanical behavior of the composite products, that, residual strength of the component can be classified by cutting depth and thrust forces and delamination. The resulting damage and reduction of product’s life due to drilling and milling induced damage call for the collective responsibility of all the manufacturing specialists to address this inherent problem in a scientific way for the benefit of the fiber reinforced epoxy user’s fraternity. Therefore, the study of the effect of the milling induced damage on the mechanical behavior of laminated composites is of paramount importance.

Furthermore, many researches were done to investigate the effect of nano particles on the mechanical properties of composites after applying machining damage. These nano composites could have many applications on the structures under load like: bridge,
wall, fuselage, ships, automotive and etc. (Tagliaferri, 1990 #1) Studied the effect of drilled specimen of glass fiber reinforced epoxy composite and also found it be independent of damage extent. The bearing strength influenced by damage and reduction in damage was accompanied by an increase in the bearing strength. (Persson, 1997 #3) Studied the effects of drilling on the strength and fatigue life of carbon/epoxy composite laminates and in order to drill a hole new Tanique called KTH method have been applied. The study was important as established the extent of damage which subsequently influenced the mechanical behavior of the specimens with drilled hole the present study is an attempts to investigate experimentally the significance of the drill geometry and operation variables (as cutting speed and feed rate) on the residual tensile strength of the drilled laminates. It is very essential to understand the mechanism of material removal and kinetic of machining process that affecting the performance of cutting tools for achieving the desire quality of machined surface. With regard to quality of machined components during drilling, the principal drawbacks are usually, surface delamination, fiber pullout, burning, fuzzing and surface roughness, and similarly many drawbacks when the laminates undergo milling operation. But since, very less number of research studies has been done on milling of CFRP and GFRP composite laminates, hence it creates a research gap to investigate the laminates under various cutting and load conditions during milling process. milling extensively used to make slots and keyways which are vulnerable to the stress concentration and source defects, thus cutting parameters such as machining force and the strength of the material must be studied. that (Davim, 2005 #4) carried out the experimentation on milling carbon fiber reinforced polymer and found that results the machining force (F) in the work specimens increase the feed rate and decreases along cutting velocity. considering the same cutting parameters (cutting speed and feed rate) they showed that feed rate is the cutting parameter which has greater influence on machining force in work piece along investigation on the machining condition of fiber reinforced polymers, Bhatnagar, have revealed that the cutting forces are dependent on the fiber angle as well as the cutting direction. Palanikumar et al. have attempted to evaluate the influence of machining parameter on surface roughness in machining GFRP composite and results that feed rate got more influence on surface roughness that followed by cutting speed. Kalla has developed a methodology for predicting the cutting forces by transforming specific cutting energies from orthogonal cutting to oblique cutting, which is capable of predicting the cutting forces in helical end milling of unidirectional and multidirectional composites laminates. The effect of cutting parameters and tool geometry using conventional machining and also on the phenomena associated with unconventional machining of composite material in order to make damage. Kishore et al. investigated the residual tensile strength of drilled uni-directional glass fiber reinforced epoxy composites using the Taguchi method to establish the optimum levels of the drill point geometry, the cutting speed and the feed rate for getting maximum residual tensile strength in drilled unidirectional glass fiber reinforced (UD-GFRP) laminates. The optimum selection of the drill point geometry was shown to be an important factor in ascertaining the minimum drilling induced damage and subsequently the maximum residual tensile strength. The residual tensile strength was found to be influenced by the operating variables and the drill point geometry.
Buckling is an important feature that designers must considerate on fabrication of laminates and composite structural design, buckling of laminated composite leads to failure and braking point due to its thickness and weight ratio (thin and light)\textsuperscript{22}. The buckling load of laminates depends on different factors that leads to failure such as, fiber orientation, laminate structure, reinforcement and boundary condition. In the present study 16 layer laminates GFRP reinforced with Nano SiO\textsubscript{2} was fabricated\textsuperscript{9}. In order to examine the damage and effected laminates by damage incur machining process (milling composite ) specimens have been tested under tensile and buckling loads which estimated the ultimate buckling point and ultimate stress point after machining and damaged impressed on Nano composite, machining impress some stresses and forces which caused to residual stress which are thrust force and feed rate and spindle speed, spindle speed and feed rate were fixed values and thrust force and depth were varied, residual stress is an important factor in engineering design which the present study looked to at first survey the effects of milling tools and thrust force and cutting depth on residual stress and ultimate both buckling and tensile stress points. Also effects of different contents of Nano particles on surface gloss and increasing the machining ability and buckling and tensile stress points thus decrease the residual stress on GFRP reinforced Nano SiO\textsubscript{2} have been surveyed.

2. Experimental details

2.1. Material details

Epoxy resin utilized in this study was EC 130LV. Its epoxide equivalent weight was 185-192 g/eqiv and provided by Shell Chemicals Co. Epon 828 is basically DGEBA (Diglycidyl ether of bisphenol-A). The curing agent was a nominally cycloaliphatic polyamine, Aradur\textsuperscript{®} 42 supplied by Huntsman Co. Nano SiO\textsubscript{2} contents used in this study as Nano reinforcement in the epoxy matrix was purchased from Institute of Petroleum Industry (RIPI) of Iran with an outer diameter 10–15 nm, purity of more than 95\% and maximum length of <30 μm that indicates in Table.1 and Table. 2, and Glass fiber were purchased from Toray Company. The solvent was Tetrahydrofuran (THF) with purity (GC) more than99\% provided from Merck Co(Germany).

<table>
<thead>
<tr>
<th>SiO\textsubscript{2} : KH550</th>
<th>Ti</th>
<th>Ca</th>
<th>Na</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>96.3+w%: 3-4w%</td>
<td>&lt;120ppm</td>
<td>&lt;20ppm</td>
<td>&lt;50ppm</td>
<td>&lt;200ppm</td>
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</table>

Table 2

<table>
<thead>
<tr>
<th>SiO\textsubscript{2} : KH550</th>
<th>Purity</th>
<th>APS</th>
<th>SSA density</th>
<th>Bulk density</th>
</tr>
</thead>
<tbody>
<tr>
<td>96.3+w%: 3-4w%</td>
<td>96.3+%</td>
<td>10-15</td>
<td>130-600m2/g</td>
<td>&lt;0.10 g/cm\textsuperscript{3}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.4 g/cm\textsuperscript{3}</td>
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</tbody>
</table>
2.2. Characterization

The critical buckling loads and tensile stress GFRP/Epoxy nanocomposite were measured experimentally. Buckling tests samples were cut with saw from original samples, the dimension of samples were in 12mm×140mm in width × length and the mean thickness of samples was 4.8 mm, the buckling and tensile test samples were tested by applying compressive loads and axial tensile stress test in axial direction using ASTMD:6641v standard and ASTMD:3039 with a loading 1mm/min. The results of these mechanical test were measured by ASTM-150 universal testing machine from Santam Material Testing Equipment Company (Iran). In each case at least five sample were tasted to compute the mean values and standard deviations. All experiments were applied in room temperature, the critical buckling load of each composite were measured before machining and after machining. Which The critical buckling load of each composite was determined from the load–displacement curves. The initial point of the load–deflection curve deviated straight line represents the critical buckling load. Fig. 1 indicates destroying the samples under buckling load.

The experiments have been carried on GFRP laminates of 4.5 mm thickness using Cemented Carbide (K10) end milling and Cylinder Radius End tools (Fig. 2) with 10 mm
diameter. The proportion of carbide phase in this tool is 80% of the total weight of the tool material. Tungsten Carbide (WC) is the most common hard phase, and Cobalt (Co) alloy as the most common binder phase. These two materials form the basic structure of cemented carbide tool. 1000 rpm of spindle speed was performed on the experiments. The controlling interface in this equipment is developed by MITSUBISHI/ FANUC. The length of X, Y and Z axis are 600 mm, 400 mm and 400 mm respectively. The fixation of the composite material and milling tool dynamometer was made as shown in Fig. 3, to ensure that the minimum vibrations occur and displacements are eliminated while machining the components. No external cooling agent was used during machining of the composite materials. A milling tool Dynamometer having three digital indicators with a maximum range of 44N was used to acquire the three orthogonal components of machining forces (F) such as Fx, Fy and Fz and thrust forces were measured and cut depth also was measured in order to examine the residual stress on specimens which cutting depth shown in Table 3. The machining was made on each GFRP specimens and the machining force was recorded and analyzed for each slot with respect to the parameters such as, thrust force and cut depth. The machined GFRP specimens are shown in Fig. 4., machining applied on specimens as the important part of composite usage in industry, aerospace parts, ark parts, which mostly thorn or hole needed, which milling were applied on specimens.

![Fig. 2 (a) End milling and (b) Cylinder Radius End tools](image-url)
Fig. 3 Controlling milling process and thrust forces were made in this process.

<table>
<thead>
<tr>
<th>Tools</th>
<th>Cut depth</th>
<th>Feed rate</th>
<th>Spindle speed</th>
<th>Max thrust force</th>
</tr>
</thead>
<tbody>
<tr>
<td>End mills</td>
<td>1mm-2mm</td>
<td>1mm/min</td>
<td>1000rpm</td>
<td>44N</td>
</tr>
<tr>
<td>Cylinder Radius End</td>
<td>1mm-2mm</td>
<td>1mm/min</td>
<td>1000rpm</td>
<td>40N</td>
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</table>
2.3 Fabrication method

The laminate plates were prepared with 16 layers in 0 orientation and different Nano SiO2 contents shown in Table 4 based on bag vacuum molding method where the cured resin was cured by Tetrahydrofuran as the solvent for all mixture components, in order to prepare each sample, different Nano contents were added to cured resin, where comparable neat epoxy samples could be prepared mixing by using of a magnetic stirrer at least two hours with 2000 RPM then in order to homogenization ultra-sonic device(ultrasonic SONOPLUS-HD3200, 50% amplitude, 20 kHz and pulsation; On for 10 s and Off for 3 s) for 8 min was applied on the matrices. At this stage 23 per (per hundred resins) of cycloaliphatic polyamine was added as hardener based on stoichiometric ratio, then all prepared matrices were molded in to 16 Glass fiber shown in Fig5, after that specimens were kept in room temperature 24 hours and then for final solidification post curing in hot over 80,150,200 respectively each for 2 h was applied and after curing of the laminates it is allowed to cool at room temperature as seen in Table5.
Table 4

<table>
<thead>
<tr>
<th>Silicon Oxide Nanoparticles SiO2 Certificate of Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2 : KH550</td>
</tr>
<tr>
<td>Ti</td>
</tr>
<tr>
<td>96.3+wt% : 3-4wt%</td>
</tr>
</tbody>
</table>

Table 5

<table>
<thead>
<tr>
<th>Nano SiO2 contents (weight percentage)</th>
<th>1wt%</th>
<th>2wt%</th>
<th>3wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber orientation (Degree)</td>
<td>0</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Post curing agent for 2h (C°)</td>
<td>80</td>
<td>150</td>
<td>200</td>
</tr>
</tbody>
</table>

Fig. 5 Molding process of matrices in to 16 layers of GF

4. Result and discussion

Nano SiO2 reinforced GFRPS were manufactured by VRTM method tested under compressive loads in two session machined and non-machined mode. The tools were used in this study respectively Cemented Carbide (K10) end milling and Cylinder Radius End tools, that the effect of machining were evaluated in order to overlook the residual stress caused by machining in fact also the Nano contents were added to understand the effect Nano particles on buckling strength growth and to reduce the effect of residual stress on eventually failures. Nano SiO2 contents were added to
matrices to increase the mechanical behavior and especially buckling loads. The machinability was evaluated by machining force on the work piece (F) the machining force value was determined by following Eq. (1). (see Fig 4)

\[ F = \sqrt{F_x^2 + F_y^2 + F_z^2} \] (1)

where Fx, Fy and Fz are the 3 orthogonal components of machining force in the work piece (F).

4.1 effect of nano particles on the buckling strength of undamaged laminates.

Figure. 6. shows the effect of Nano silica contents on the buckling strength of the laminates. Also, the laminates of this section are Non-milled and have no hole. According to this figure it can be obtain that the buckling strength of the epoxy/GF laminates were increased with increasing the silica content up to 2 wt% but brought negative effects by adding 3wt% which caused to buckling point decreases. This can be explained by the nature of the silica that can disperse on the epoxy matrix and make a strong bonding with the epoxy that lead to a smooth surface.
Figures 7(a) and (b) show the scanning electron microscopy (SEM) pictures of epoxy/GF/Silica laminate. As seen, the nano particles of silica have been dispersed well in all surface of epoxy and made a strong bonding with matrix. According to these figures it is obvious that the Silica elements distributed uniformly.

4.2 Influence of end mill tool on machining force in milling of GFRP with presence of Nano Sio2

as shown in Fig 4 and Fig5 end mill tool was applied on GFRPS by constant spindle speed and feed rate as shown in Table 3. The graph shows the history of machining force with constant feed rate and spindle speed. it is realized from curves that the machining force as shown in Fig6 kept on increasing while spindle speed and feed rate were constant, its considered that presence different contents of Nano Sio2 kept on increasing the machining force when particular feed rate and spindle speed were constant, it’s found that increasing of Nano particles caused to increase the machining forces also can be implied that adding 3wt% of Nano Sio2 in to matrices caused to machining forces increase up to 44N this why the high density of 3wt% Nano Sio2 crystalline structure made machining process harder and caused more forces that reduced the mechanical properties but adding 2wt% of Nano particles can causes less machining Force in compare to 3wt% Nano particles thus according to figures 9 and 10 , adding 3wt% Nano Sio2 causes reduction in buckling point and also can be implied that adding Nano Sio2 up to 2wt% can increase buckling point , but applying end mill
tool on specimens is considerable which in comparing two levels of Nano particles 2 and 3 wt% with considering thrust forces on them it is obvious by adding 3wt% buckling point 20% decreased its because of more residual stress caused by thrust force in machining process but must be mentioned that depth of hole can has significant buckling reduction which comparing 1mm depth to 2mm buckling points reduced 20% it is obvious that depth of each hole has significant effect on buckling point . as shown in Fig. 8 &9 adding 2 wt% of Nano Sio2 caused better serenity in compare to neat epoxy one .in the other word adding 2 wt% of Nano Sio2 cause to increase the machining force but also cured the machining surface with well serenity neat epoxy one with constant feed rate and spindle speed but adding 3wt% Nano Sio2 causes negative effects in compare to 2wt%. Its shown that despite of machining parameter on machining force increasing we can also overlook the fabrication method and fabrication parameter such as addition like Nano particles.

Fig. 8 Effect of applying end mill tools with 1mm depth on specimens with different contents of Nano Sio2
4.3 Influence of Cylinder Radius End tool on machining force in milling GFRP with presence of Nano SiO2

As shown in Fig.9. Cylindrical radius end tool was applied on GFRP specimens in order to evaluate the machining force while the spindle speed and feed rate stayed constant as shown in Table 3. Also the graphs show the history of machining force increasing while the feed rate and spindle speed stayed constant. As seen in Fig. 9. Compare to end mill tool, applying Cylinder Radius End tool on specimen causes different behavior, that by pervade in specimen and act on specimen machining forces were different while the spindle speed and feed rate stayed constant. it's how the machining force showed different behavior with compare to end mill tool, it shows that applying cylinder radius end tool have less machining force with increasing than end mill one. Also it can be implied that significant effect of Nano SiO2 on machining force is totally undeniable , which by adding different contents of Nano SiO2 (respectively neat,1%,2%,3%) increase the machining force. But it is still less than maximum rate of machining force made by end mill as shown in Fig 6 which maximum rate of thrust force for end mill tool is 44 N and for Cylindrical radius end is 39N.
Fig. 10. Adding Nano silica up to 3wt% caused to thrust force (machining Force) increase in two depth 1mm and 2 mm

It can be mentioned that adding 3wt% Nano SiO2 increases the thrust force which can causes more residual stress on specimens again as we mentioned above. Because of high density of the 3wt% Nano SiO2 crystalline structure, made machining process tougher which this caused to reduce the buckling point 10%. This is how the role of residual stress must be considered significantly. According to Figures 8, 9 and 10 must be mentioned that applying cylindrical radius end tool left less destructive effects than end mill tool. It is obvious that 2wt% of Nano SiO2 is the optimum level that even by applying Cylindrical radius end in depth of 1mm had 5% reduction compare to Non-milled one and it can be implied that Cylindrical radius end caused less micro cracks than end mill during milling process which shown in Fig. 9.

As thrust force and depth which caused 39 N force can causes less residual stress and less buckling reduction after milling process than end mill tool and thus depth of milling process on the specimens. It is considerable which by increasing milling depth, thrust force increased significantly which this caused more residual stress on milled specimens. Also effect of Nano in this enhancement is totally undeniable which by adding Nano particles to Neat Epoxy (1, 2, 3 wt% respectively) thrust force increased thus in two depth, adding 2wt% was the optimum buckling point but 3wt% had negative effect and decreased buckling point.

As shown in Fig. 10 it can be mentioned that by adding different contents of Nano SiO2 to specimens, clearly can be found that surface serenity directly depends on Nano contents which Neat epoxy got less serenity and well serenity dedicate to 2% Nano SiO2 as shown in Fig. 10.
Fig. 11 AFM pictures of laminates contains: (a) 3 wt%, (b) 2 wt%, (c) 1 wt% silica and (d) Neat Epoxy/GF laminate. (effect of different contents of Nano SiO2 on surface serenity after milling process)

Compare to end milled specimens, cylinder radius end machined place got better surface serenity and also can be mentioned that adding Nano contents had been effective to obtain surface serenity in addition both Fig. 11. And 12 micro crack on the surface are obvious and also refer to Fig. 10. Cylindrical radius end tool caused less micro cracks.in comparing two tools can be found that cylinder radius end got better surface serenity and less machining forces and can be better choice to apply on specimens as machining factor and also can be mentioned that despite all machining factor such as spindle speed, feed rate, fabrication factors such as different contents of Nano particles, Fiber orientation, composite fabrication method, can play important and undeniable role in machining process, that these factors must be considered.

According to the SEM pictures of the crack around the hole, before and after buckling test, it can be seen that the Nano silica had a preventive role on the crack growth. (Figures 13 & 14)
Fig. 12 Effect of Cylindrical radius end tool on milling of specimens and its milling surface serenity AFM pictures of laminates contains: (a) 3 wt%, (b) 2 wt%, (c) 1 wt% silica and (d) neat Epoxy/GF laminate

Figures 13 and 14 show the crack growth around the hole of the end mill and Cylindrical Radius End respectively. As seen, the growth of crack in laminates that were milled with End mill tool caused more micro cracks in compare with the other. As has been mention in past sections, this manner can be explained by the nature of the tool and its more destructive effects and more thrust force on specimens which caused more residual stress that increased the number of micro cracks in compare to Cylindrical radius end tool. Also it can be seen that the Nano silica around the hole has a restraining role against the crack growth. The reason might be that the Nano particles of silica with matrices which it means than the Nano particles played curing agent into crack areas which cured the cracks and made the crystalline connection to cover the cracks and make structure stronger than Neat Epoxy milled one, Nano particles filled the crack gaps and crack lines which this role can be mention as curing agent.
Fig. 13 (a) crack before test   (b) crack after test with **End-mill milling tool**.

Fig. 14 (a) Crack before test   (b) crack after test with **cylindrical radius end tool**.
4.4 Influence of Machining Factors and Nano SiO₂ on Buckling Strength

After considering the machining forces and influence of Nano SiO₂ on specimens, all specimens were tested under buckling loads as shown in Figures 15-17 with 2 hole depths as shown in Table 3. The results showed that adding Nano particles significantly growth the buckling strength that 2wt% of Nano SiO₂ had the most important influence on buckling strength growth, and also it had the most influence on residual stress reduction.

We also must consider the undeniable role of Machining factors on residual stress and Buckling Strength reduction, it showed that applying end mill tool on specimen reduce the Buckling strength growth. Thus adding Nano SiO₂ can heal the machining specimen by moving on weak part as shown in Fig 17. Also adding Nano SiO₂ increase the buckling point same increase the surface serenity after machining process. According to Figures 15-17, magnitude of buckling load increase by increase of Nano SiO₂ contents up to 2%, and then decrease by adding more than 2wt% which means that adding Nano particles more than 2wt% causes negative effects which it means that increasing Nano SiO₂ more than 2% results negatively and decrease the buckling load while surface serenity increases, but about fiber orientation 0 fiber orientation have been chosen due to its well history of buckling strength, it can be concluded that 2wt% Nano SiO₂ can be a wise choice in order to same to have good buckling strength and well serenity and well machining process.

Fig. 15 Effect of Cylindrical radius end tool on buckling point with machining depth of 1mm
Fig. 16 Effect of Cylindrical radius end tool on buckling point with machining depth of 2mm

Fig. 17. Effect of Nano SiO2 on the machining force in two depth 1mm and 2mm
Fig. 18. Comparing the effect of applying milling tools (Cylindrical radius end, End mill) on:
(a) Neat specimens, (b) 1wt%, (c) 2 wt% and (d) 3 wt% of silica.

5. Conclusion
In the current study, the effect of nano silica on the buckling strength of epoxy/glass fiber hybrid composite laminates was investigated before and after applying damage. For this purpose, 3 different amount of nano silica (1-3 wt%) was added to epoxy and 16 layers of glass fiber were laid-up by vacuum resin transfer method (VARTM). Two kinds of milling tools, (cylindrical and End-mill) were used in order to make a hole in the center of laminates with two depth of 1 and 2 mm. according to the results, it was found that adding nano silica to the epoxy had a significant effect on the buckling strength of laminates and the samples with 2 wt% of silica had the better strength in compare with
the other. Also, it was obtained that the End mill tools could reduce the strength of the laminates more than the cylindrical radius end tool but the silica particles had a preventive role on the growth of crack in damaged laminates and the buckling strength of the milled laminates were increased about 35% in compare with the neat-Epoxy Non-milled laminates. Finally, the results showed that when the silica particles increased more than 2 wt% of composites it was lead to the saturated matrix and reduce the strength.

References