Experimental investigation on the mechanical properties of glass fiber reinforced nylon

2016 IOP Conf. Ser.: Mater. Sci. Eng. 114 012118

(http://iopscience.iop.org/1757-899X/114/1/012118)

Experimental investigation on the mechanical properties of glass fiber reinforced nylon

D M Nuruzzaman[1], A K M Asif Iqbal[2], A N Oumer[3], N M Ismail[2] and S Basri[2]

[1,2] Faculty of Manufacturing Engineering, University Malaysia Pahang, Malaysia
[3] Faculty of Mechanical Engineering, University Malaysia Pahang, Malaysia

E-mail: dewan052005@yahoo.com

Abstract. In this study, the influence of different weight percentages of glass fiber (GF) reinforcement on the mechanical properties of nylon (PA6) composite is investigated. Test specimens of pure nylon, 95% nylon + 5% GF, 90% nylon + 10% GF, 85% nylon + 15% GF and 80% nylon + 20% GF are prepared using an injection molding machine. In the experiments, tensile tests and impact tests are carried out. The obtained results reveal that mechanical properties of the nylon composites are significantly influenced by the weight percentage of glass fiber. From the tensile test results, it is observed that pure nylon has the lowest elastic modulus and yield strength whereas 80% nylon + 20% GF composite shows the highest elastic modulus and yield strength. Moreover, pure nylon shows the lowest tensile strength while 80% nylon + 20% GF shows significantly improved tensile strength. Results show that elongation at break is remarkably high for pure nylon whereas it is very low for 80% nylon + 20% GF. Izod impact test results reveal that, 85% nylon + 15% GF composite has the highest impact strength or toughness whereas 95% nylon + 5% GF composite shows the lowest impact strength. Furthermore, 80% nylon + 20% GF composite shows somewhat less impact strength or toughness than 85% nylon + 15% GF composite.

1. Introduction

Nowadays fiber reinforcement polymer composites are gaining popularity and these polymer composites are finding ever increasing usage for a wide variety of industrial applications such as bearing material, cams, rollers, gears, wheels, pistons rings, mechanical seals, clutches etc. where their self-lubricating properties are exploited in order to avoid the need for any lubrication. In the past decade, many researchers made considerable efforts for better understanding the mechanical and tribological properties of polymer composites reinforced with different types of fibrous materials [1-9]. In recent years, fiber reinforced polymer composite has been the topic of interest in industries such as aerospace and automotive industries. These polymer composites generally exhibit high levels of stiffness, high strength-to-weight ratio, high modulus, outstanding fatigue resistance, very impressive corrosion and wear resistance as compared to common metal/alloys, such as steel and aluminum alloys. Different parameters such as content of the reinforcement, shape, size and direction of reinforcement, type of the reinforcement and matrix, processing technique etc. can influence the properties of the polymer composites.

[1] Corresponding author

In recent times, glass fiber (GF) and carbon fiber (CF) are widely used as reinforcement material to enhance the strength and stiffness of the polymer-based composites. The influence of carbon fiber reinforcement on the mechanical and tribological properties of polyamide6/polyphenylene sulfide (PA6/PPS) composites was investigated [10]. The obtained results show that the modulus, strength and hardness of PA6/PPS composites are improved although breaking elongation rate and impact strength decrease to some extent. Results also show that friction coefficient of PA6/PPS-CF composites is lower than that of pure PA6/PPS blend and the wear rate of the PA6/PPS-CF composites trends to increase with the increase in the content of carbon fiber but wear resistance of PA6/PPS-CF behaves better under high load and high speed conditions. The effects of different fiber types on the mechanical and impact properties of short fiber reinforced polypropylene composites were investigated [11]. The effect of fiber length on the composite properties was also analyzed. In general, all the composites showed significant improvements in the properties compared to the pure polymer matrix. The use of a coupling agent showed that fiber/matrix interaction has significant impact on the composite properties. Mechanical and thermal properties of jute and glass fiber reinforced epoxy hybrid composites were investigated [12]. The obtained results show that the addition of jute fiber and glass fiber in epoxy increases the density, tensile strength, impact energy and flexural strength. In addition, the composites show different behavior in terms of mass loss which is a function of temperature and the percentage of jute fiber or glass fiber reinforcement. Repeated impact response of E-glass fiber reinforced polypropylene and epoxy matrix composites was investigated and it is concluded that resin type is a very important parameter for the repeated impact response of the composites [13]. Influence of hybrid carbon nanotube (CNT)/glass fiber (GF) reinforcement on the properties of polypropylene composites was investigated and test results revealed that CNT and GF reinforced hybrid composites exhibited better tensile modulus and tensile strength than only CNT or GF reinforced composites [14].

In this study, glass fiber was used as reinforcement with nylon for making glass fiber reinforced nylon composite specimens using the injection molding process. Tensile tests were carried out using pure nylon and 5% to 20% GF content of nylon composite specimens to investigate the influence of glass fiber content on the mechanical properties of the nylon composites. The influence of different weight percentages of glass fiber on the impact strength of nylon composites was also examined.

2. Experimental

Test specimens were prepared using an injection molding machine (NISSEI PNX 60). Standard dogbone shaped specimens (pure nylon and nylon composites of 5%, 10%, 15% and 20% glass fiber content) were injection molded according to the ASTM D638 specifications for tensile testing (reinforced and unreinforced plastics). The mechanical properties of pure nylon and nylon composites involve its behavior under stress. Tensile testing was used to find the most important mechanical properties. Tensile tests of the specimens were carried out using universal test machine Instron (model: 3369, maximum load capacity: 50 kN). Mechanical properties such as tensile or elastic modulus, yield strength at 0.2% offset, ultimate tensile strength (UTS), breaking or rupture strength and tensile elongation at break were observed for pure nylon and nylon composites of different weight percentages of glass fiber reinforcement. Impact tests were designed to measure the resistance to failure of the nylon composite to a suddenly applied force. The impact energy or energy absorbed prior to failure was measured for each type composite specimen. This amount of energy that the specimen absorbed during the entire impact test – from start to end, is an indicator of ductility or toughness of the composite. Izod impact tests were carried out using Instron Impact Pendulum (Model CEAST 9050). All the experiments were conducted according to ASTM D4812 standard using unnotched specimens. Each specimen was held as a vertical cantilevered beam and was broken by the striker or pendulum. The impact strength or energy absorbed by the test specimen was equated with the energy lost by the pendulum. For tensile or impact testing, each test was repeated five times to ensure the reliability of the test results and the average values of these results were taken into consideration.

3. Results and discussion

Figure 1 shows the elastic or tensile modulus for different percentage compositions of glass fiber reinforced nylon composite. Elastic modulus is a measure of the stiffness of a solid material and this modulus value measures the resistance of the material to be deformed elastically under tensile force. From the obtained results of tensile test under 3 mm/min strain rate, pure nylon reveals low elastic modulus 0.84 GPa. It can be seen that 95 % PA6 + 5 % GF nylon composite exhibits an increased elastic modulus 1.3 GPa which is about 55 % higher than that of pure nylon. For 10 % addition of glass fiber, the composite shows the elastic modulus 1.96 GPa which is about 132 % higher than that of pure nylon. It is observed that 85 % PA6 + 15 % GF composite shows an increased elastic modulus 2.26 GPa which is about 169 % higher than that of pure nylon. If the glass fiber content is further increased to 20 %, it is observed that the composite shows significantly increased modulus 3.6 GPa which is about 329 % higher than that of pure nylon. Generally a higher value of tensile stress and lower value of tensile strain produces a higher value of tensile modulus which indicates that as the fiber percentage increases, the degree of resistance to deformation increases which consequently increases the stiffness of the material.

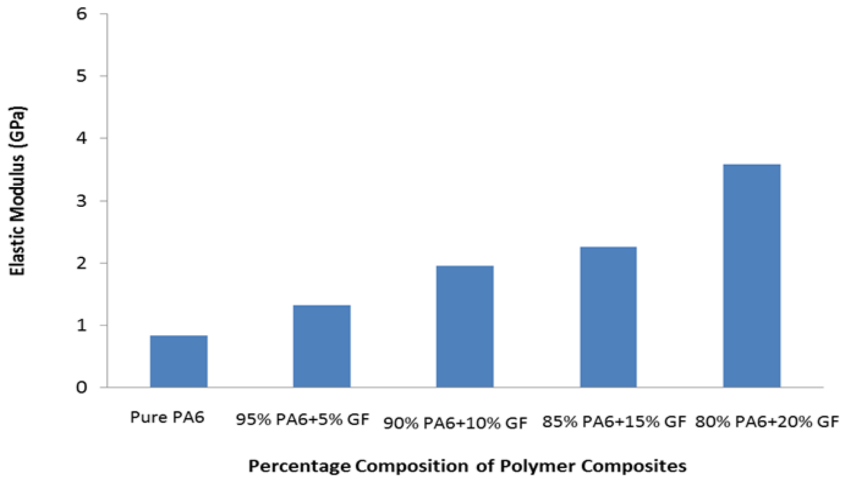

Figure 1. Elastic modulus for different percentage compositions of glass fiber reinforced nylon composites

Figure 2 shows the yield strength or yield point (0.2% offset) for different percentage compositions of glass fiber reinforced nylon composite. These results are obtained from the tensile experiments carried out under extension rate or ramp rate of 3 mm/min. This is the stress level at which each material composition begins to deform plastically. The obtained result reveals that pure nylon containing 0% GF begins to undergo permanent or plastic deformation at low yield stress level 15 MPa. From the obtained results it is apparent that for the addition of 5% weight percentage of glass fiber to 95% pure nylon, yield strength of the composite increases to 19.1 MPa which is about 27% higher than that of pure nylon. From the figure it is also clear that 90% PA6 + 10% GF polymer composite exhibits an increased yield strength 27.6 MPa which is 84% higher than that of pure nylon. When the weight percentage of GF is further increased to 15%, yielding of the composite occurs at 33.4 MPa which is about 122% higher than the yield strength of pure nylon. Finally, in the nylon composite when the content of GF is increased to 20%, yield strength of the composite is remarkably increased to 49.5 MPa which is 230% higher than that of pure nylon. Due to the increased weight percentage of glass fiber in the nylon composite, initiation of plastic deformation occurs at higher stress level. Therefore, the increased content of glass fiber in the nylon composite shows significant improvement in the yield strength of the composite.

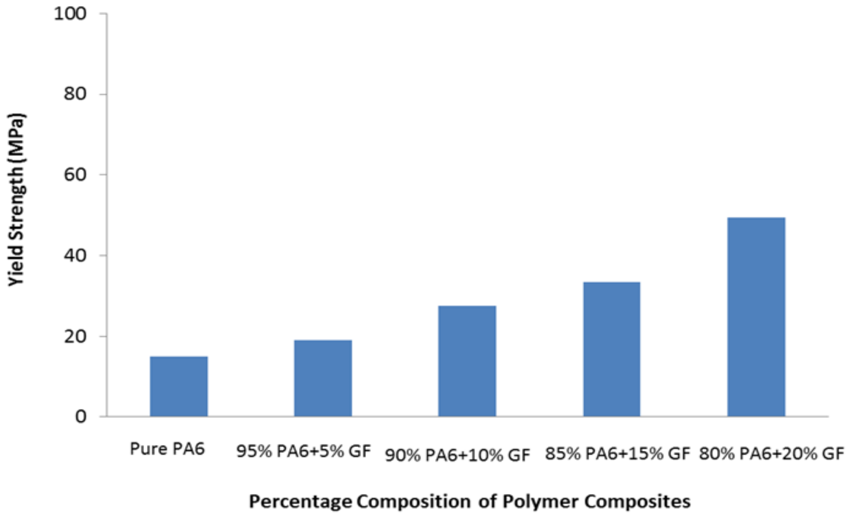

Figure 2. Yield strength (0.2% offset) for different percentage compositions of glass fiber reinforced nylon composites

Figure 3 shows the ultimate tensile strength (UTS) or tensile strength (TS) of the nylon composite of different percentage compositions of glass fiber. Tensile strength is the intensive property of the composite which is the maximum stress that the composite withstands while being stretched before failure occurs under a strain rate or ramp rate of 3 mm/min. The obtained result reveals that tensile strength of pure nylon is 37.3 MPa and this is the stress point where onset of necking started before fracture. For 95% PA6 + 5% GF, the tensile strength is 44.2 MPa which is 18.5% higher than that of pure nylon. For the 10% GF nylon composite, tensile strength shows higher value 53.6 MPa. For further increase of glass fiber content to 15%, the composite also shows higher tensile strength 57.8 MPa. Finally, it is observed that 80% PA6 + 20% GF composite shows significantly increased tensile strength 79.5 MPa which is about 113% higher than that of pure nylon. It is believed that as the fiber load i.e. glass fiber content increases, good interfacial bonding between the fiber and nylon consequently produces higher strength.

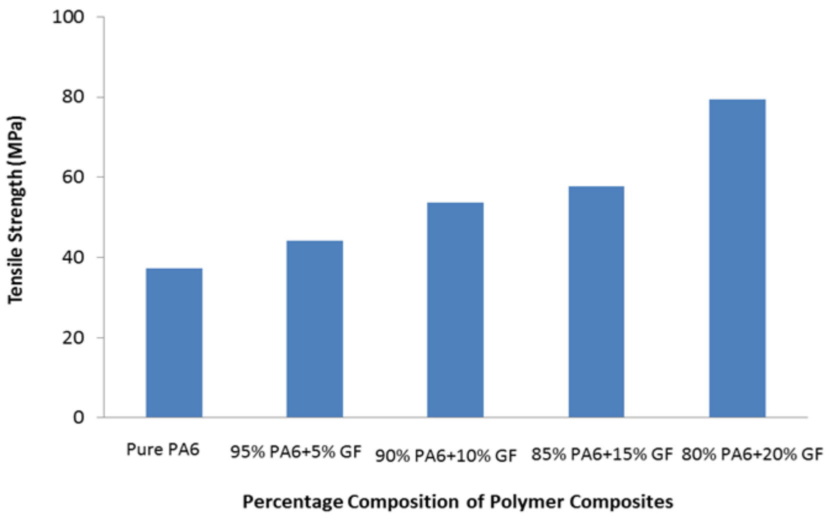

Figure 3. Tensile strength for different percentage compositions of glass fiber reinforced nylon composites

Figure 4 shows the breaking strength or fracture strength of nylon composites of different percentage compositions of glass fiber. It is observed that pure nylon shows the breaking strength 26.5 MPa. It can be seen that for the weight percentage of glass fiber content 5%, 10%, 15%, and 20%, the fracture strength of the composite shows 35.3, 47.7, 54.7 and 68.8 MPa respectively. Comparing these results with the results of figure 3, it is apparent that the breaking strength of nylon composites is lower than the tensile strength as the nylon composites behave as ductile material.

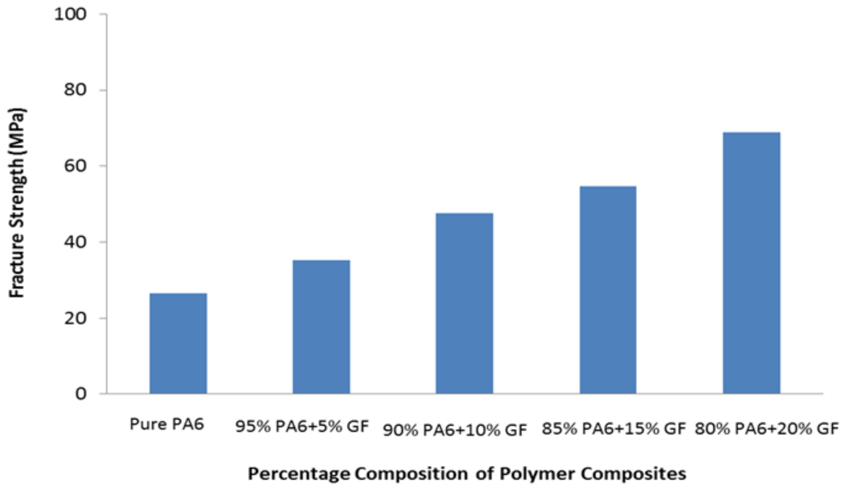

Figure 4. Fracture strength for different percentage compositions of glass fiber reinforced nylon composites

Figure 5 shows the tensile elongation at break or fracture strain of nylon composites of different percentage compositions of glass fiber. It is the amount of strain that the nylon composite experiences before failure under a strain rate of 3 mm/min. It is observed that pure nylon experiences a very high tensile elongation before failure which is about 84%. It means that pure nylon deforms plastically by absorbing very high energy before failure. The obtained results reveal that for the weight percentage of glass fiber content 5%, 10%, 15%, and 20%, the elongation at break is about 27%, 20%, 14% and 6% respectively which is much lower than that of pure nylon. It is apparent that as the fiber load or weight percentage of glass fiber content increases, the elongation at break gradually decreases. It is also noticed that for the 20% GF nylon composite, the elongation at break reduces significantly. The tensile elongation to failure is a measure of the ductility of the nylon composites. It is believed that for high percentage of glass fiber content, the composite shows ductile-brittle transition behavior.

Figure 6 shows the impact energy or impact strength of nylon composites of different percentage compositions of glass fiber. Impact energy is the measure of the work done or energy absorbed by the nylon composite prior to fracture. During impact test, when the striker impacts the composite specimen, the specimen absorbs energy until the yield point, then the specimen begins to undergo plastic deformation by absorbing energy and work hardening occurs at the plastic zone, and when the composite can absorb no more energy, eventually failure occurs. Impact strength is a relative measure of the impact toughness of nylon composites of different percentage compositions of glass fiber. It is observed that 5% glass fiber nylon composite can absorb 4.5 J before failure occurs. For 10% addition of glass fiber, the composite shows the impact strength 5.4 J which is 20% higher than that of 5% GF composite. If the addition of glass fiber increased to 15%, the composite shows increased impact strength 6.4 J which is about 42% higher than that of 5% GF composite. Finally, it is observed that for the 20% addition of glass fiber, the composite shows reduced impact strength 4.7 J which is about 27% lower than that of 15% GF composite. It is apparent that due to high amount of glass fiber addition (20%), the impact energy drops off significantly. It is obvious that due to the increased amount of glass fiber addition such as 20% GF, the composite shows reduced impact strength, means that the composite behaves as ductile to brittle transition and lower impact toughness.

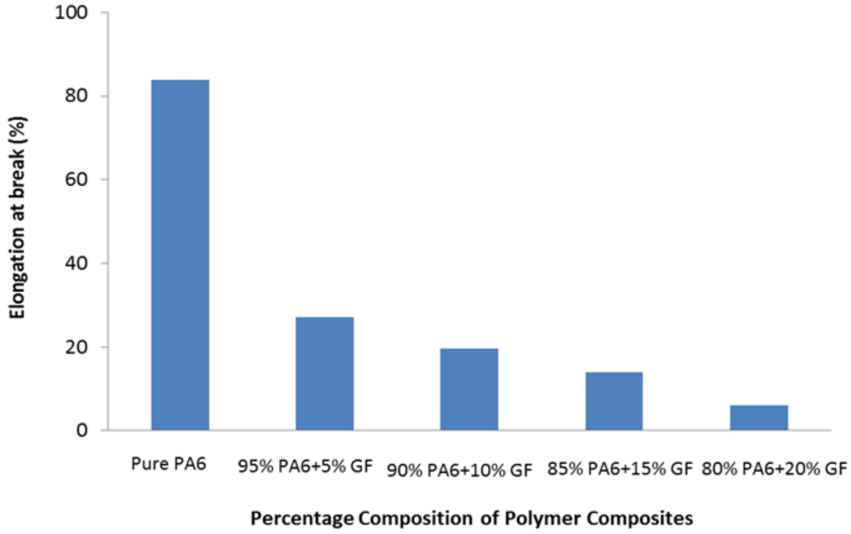

Figure 5. Tensile elongation at break for different percentage compositions of glass fiber reinforced nylon composites

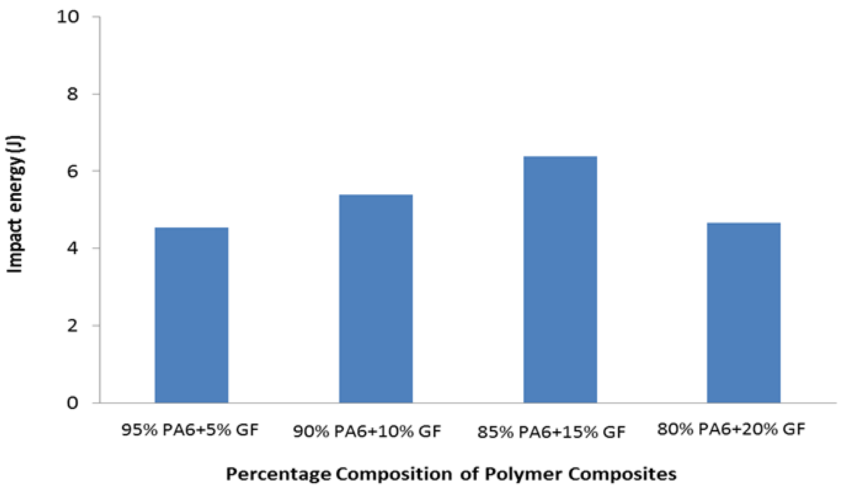

Figure 6. Impact energy for different percentage compositions of glass fiber reinforced nylon composites

4. Conclusion

The influence of different weight percentages of glass fiber reinforcement on the tensile and impact properties of nylon composites was investigated. The following conclusions are drawn from the present research study:

1. Pure nylon shows the lowest stiffness or tensile modulus and the nylon composite shows gradual improvement in the tensile modulus with the increased content of glass fiber up to 20%. Moreover, pure nylon shows the lowest yield strength which also increases gradually with the increased weight percentage of glass fiber in the nylon composites.

2. Pure nylon shows the lowest tensile strength which increases gradually with the increase in glass fiber content of the nylon composites. However, 20% glass fiber nylon composite shows significantly improved tensile strength. The elongation at break is remarkably high for pure nylon while it is low for nylon composites, particularly, it is very low for 20% GF nylon composite.
3. Izod impact test results show that 5% GF nylon composite has the lowest impact strength while 15% GF composite has the highest impact resistance or toughness. On the other hand, 20% GF nylon composite shows reduced impact strength or toughness.

5. References

[1] Suresha B, Ravi Kumar B, Venkataramareddy M and Jayaraju T 2010 Role of micro/nano fillers on mechanical and tribological properties of polyamide66/polypropylene composites *Mater. Des.* **31** 1993–2000
[2] Yuan L, Ma X, Liang G and Yan H 2007 Fibre reinforced organic rectorite/unsaturated polyester composites *Compos. Sci. Technol.* **67** 2311-22
[3] Mouhmid B, Imad A, Benseddiq N, Benmedakhene S and Maazouz A 2006 A study of the mechanical behaviour of a glass fibre reinforced polyamide 66: Experimental investigation *Polym. Test.* **25** 544-52
[4] El-Tayeb N S M, Yousif B F and Yap T C 2006 Tribological studies of polyester reinforced with CSM 450-R-glass fiber sliding against smooth stainless steel counterface *Wear* **261** 443–52
[5] Mimaroglu A, Unal H and Arda T 2007 Friction and wear performance of pure and glass fiber reinforced poly-ether-imide on polymer and steel counterface materials *Wear* **262**1407–13
[6] Unal H, Sen U and Mimaroglu A 2006 An approach to friction and wear properties of polytetrafluoroethylene composite *Mater. Des.* **27** 694-99
[7] Chowdhury M A, Nuruzzaman D M, Roy B K, Samad S, Sarker R and Rezwan A H M 2013 Experimental investigation of friction coefficient and wear rate of composite materials sliding against smooth and rough mild steel counterfaces *Tribol. Ind.* **35** 286-296
[8] Nuruzzaman D M, Chowdhury M A and Rahaman M L 2011 Effect of duration of rubbing and normal load on friction coefficient for polymer and composite materials *Ind. Lubr. Tribol.* **63** 320-26
[9] Nuruzzaman D M, Rahaman M L and Chowdhury M A 2012 Friction coefficient and wear rate of polymer and composite materials at different sliding speeds *Int. J. Surf. Sci. Eng.* **6** 231-45
[10] Zhou S, Zhang Q, Wu C and Huang J 2013 Effect of carbon fiber reinforcement on the mechanical and tribological properties of polyamide6/polyphenylene sulfide composites *Mater. Des.* **44** 493–99
[11] Unterweger C, Bruggemann O and Furst C 2014 Effects of different fibers on the properties of short-fiber-reinforced polypropylene composites *Compos. Sci. Technol.* **103** 49-55
[12] Braga R A and Magalhaes P A A 2015 Analysis of the mechanical and thermal properties of jute and glass fiber as reinforcement epoxy hybrid composites *Mater. Sci. Eng. C* **56** 269-73
[13] Arikan V and Sayman O 2015 Comparative study on repeated impact response of E-glass fiber reinforced polypropylene & epoxy matrix composites *Composites: Part B* **83** 1-6
[14] Karsli N G, Yesil S and Aytac A 2014 Effect of hybrid carbon nanotube/short glass fiber reinforcement on the properties of polypropylene composites *Composites: Part B* **63** 154-60