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An Experimental Study of Torsional Properties of Polyvinylchloride

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Abstract: ***In this research, an experimental study has been performed to investigate the mechanical properties through torsion testing of polyvinylchloride (PVC) polymer specimens. For the purpose of the experimentation, specimens of PVC round bars have been prepared. Torsion testing machine apparatus of 200 Nm motor driven was used to evaluate the torsion properties of the tested bars. The apparatus provides four deformation speeds of 50°/min, 100°/min, 200°/min and 500 °/min. The tests conducted under different conditions in a room temperature and cooling of the samples and tested at different deformation speeds given by the torsion apparatus. Various tests produce the torsional moment- angle of rotation diagrams and thereafter both of torsional fracture resistance and shear modulus have been calculated. The results showed the effect of temperature change on the mechanical properties of PVC by making the material harder and can resist higher value of the applied torque where the range is from 2.9 N.m for the cooled sample to 2 N.m for the received samples tested at room temperature. Moreover the results showed an increase of shear modulus to 282 MPa for the cooled samples in compare to 140MPa for as received samples. Finally the results provide a guideline for designers on how to use parts made of PVC in different applications where the range of both the maximum torque and failure torque with their mechanical properties of rigidity and torsional resistance were recorded.***

Keywords: Polyvinylchloride, Torsion test, Torsional moment, Angle of rotation, Shear modulus.

1. INTRODUCTION

Among the featured properties of polymers are their light weight and ductile nature. Polyvinylchloride (PVC) is a thermoplastic polymer linear in structure and contains 50% chloride [1]. Normally PVC is a hard and rigid material. To give a flexible form to it, plasticizers are added [2]. Today PVCis considered the third largest selling plastic type in the world after polyethylene and polypropylene. This is due to its typical features of low cost and excellent durability. PVC polymer is used in various types of industries such as transport, health care, IT, textiles and constructions [3]. The mentioned typical features of the PVC encouraged the researches to investigate experiments to get better usage conditions in different applications.

Sugumaran [1] carried out an experimental study on mechanical properties and dielectric strength test of PVC cable insulation. In this study, the properties of PVC polymer were reinforced by adding particular fillers. The results were compared to the PVC resin. The experimental results showed an impact of the adding fillers on the mechanical properties of PVC such as higher value of elongation in compare to base PVC.

Kemari et al. [4] investigate the impact of the accelerated thermal aging on the dissipated energy through the insulating material of PVC used in low voltage cables insulation. Two level temperature of 80 ºC and 120 ºC were used in the experiments. Both the variation of mechanical properties and dissipated energy were examined. The results showed an increase of the dissipated energy due to material degradation.

The mechanical and electrical properties of composite material by adding fillers to the base polymer were presented by Sunanda et al. [5]. Universal tensile testing machine used to conduct the mechanical tests and find out the stress, elongation, extension, tensile yield stress, strain and tensile strength of the tested samples. The results explained that the inclusion of the nano fillers reduced both tensile strength and elongation at break point of the base polymer. In addition, it was found that the hardness of the base polymer increased with an increase of nano filler concentration.

Bishay et al.[6] investigate the mechanical, electrical and thermal properties of PVC filled with aluminum powder. The tests conducted at temperature range from 30 to 98 ºC. It has shown that the mechanical strength decreases with an increase of aluminum powder concentration. Wang et al. [7] explore the properties of adding multi-layer graphene to PVC. The tests include tensile behavior, and thermal properties. They found that the presence of graphene increase the tensile modulus and glass transition temperature.

Colloca et al. [8] conduct experimental study of closed cell PVC foam with different densities. The experimental results show that there is a highly dependent relationship between the foam density and the mechanical properties including strength, energy absorption, and elastic modulus.

The mechanical properties of reinforced PVC were studied by Ashori et al. [9] through the effect of filler form and content. Different types of wood flour and pulp fiber was used. It found that the tensile strength improved by adding these fillers.

The effect of torsional disorder and chemical defects in polymers were studied theoretically in a research work by Grozema et al. [10]. A quantum mechanical model was used to calculate the mobility of charges. The model included the effects of torsional disorder on mobility of charges on the polymer chain. The results from the comparison between the theoretical model and experimental tests show that the influence of polymerization defects finite polymer chain length cannot be neglected.

Ghobarah et al. [11] conduct an experimental investigation to improve the torsional resistance of reinforced concrete beams using fiber- reinforced polymer fabric. Both glass and carbon fibers were used in the torsional resistance upgrade and different wrapping were evaluated.

Stress relaxation of PVC measured in a research work presented by Povolo et al. [12]. The tensile and strain relaxation tests were done using tensile tester at different temperatures below the glass transition temperature of PVC.

From the reviewed literature it can be concluded that the investigations to improve the PVC properties attract the attention of researchers and the current work is an attempt to evaluate the mechanical properties throughtorsion tests of PVC under different conditions of temperature variations and deformation speeds to find the best range of utilizing PVC in practical applications.

The rest of the paper is organized as follows. Section 2 presents the methods and material, the experimental setup and procedure of the experiments. Section 3 details the results obtained from the different runs of the experiments followed by the discussion of the results. Finally Section 4 concludes the findings of the experiments and recommendations for future work.

2. METHODS AND MATERIALS

2.1 Material

The samples for torsion tests are manufactured from raw material of PVC bars of 25 mm diameter provided by local market. Both lathe and vertical milling machines are used to cut the bars to the standard shape shown in Figure 1. Screen shoot of the PVC sample is shown in Figure 2.

2.2 Experiment

The WP 510 torsion testing unit (WP 510, 200 Nm motor driven, provided by GUNT company [13]) is used to test the torsion of various types of materials. The samples can be stressed to the point of fracture. The testing moment as well as the angle of rotation is measured. It is also possible to set different deformation speeds (50°/min, 100°/min, 200°/min and 500 °/min). The unit is prepared for connection to a PC.

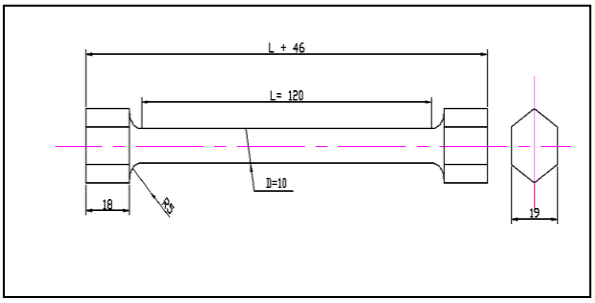

Figure 1 Standard torsion sample (dimension in mm)

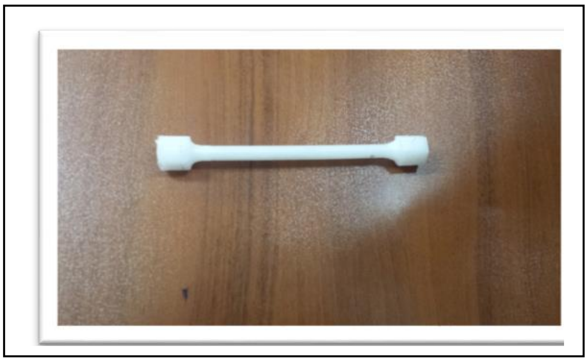

Figure 2PVC torsion sample

During the torsion test a sample is subjected to stress via a torsional moment (torque). Shear stresses occur in the sample which distorts it. To assess the torsion test, the torsional moment is plotted against the torsion angle [13]. Table1 shows the categories of the samples used in different tests. The first group tested as it is samples in the room temperature while the second group tested after they have been cooled to -18 ˚C in a refrigerator.

Table 1 Categories of the tested samples

Sample no.	Test condition	Deformation speed °/min
PVC 1	As it is at room temperature	50
PVC 2	As it is at room temperature	100
PVC 3	As it is at room temperature	500
PVC 4	Cooled to -18 ºC	100
PVC 5	Cooled to -18 ºC	500

circular cross-section of the manufactured PVC samples, the polar moment of inertia (J) is calculated by equation

2. During the various tests of PVC samples, the failure moment (M_{tb}) is recorded and used to find the torsional fracture resistance τ_b(Equation 3).

$$\tau = \frac{M_t}{J} \quad (1)$$

$$J = \frac{\pi}{32} d^4 \quad (2)$$

$$\tau_b = \frac{M_{tb}}{J} \quad (3)$$

In the elastic range of torque-angle of rotation curve, shear modulus is calculated using equation 4.

$$G = \frac{32\, M_t\, L}{\pi\, \varphi\, d^4} \quad (4)$$

Where L is the sample length, d is the sample diameter (Figure 1) and φ is torsion angle.

3. RESULTS AND DISCUSSION

The aim of this work is to monitor and find the mechanical properties- torsion of PVC polymer under different conditions of temperature variations and deformation speeds. For this purpose, PVC specimens of round bars according to standards were prepared using lathe machine and vertical milling machine.

The results show that the range of the maximum applied torque used was from 2 to 2.7 N.m for the samples tested at room temperature and from 2.6 to 2.9 N.m when the samples cooled to -18 °C.

The relationship between torque and angle of rotation for the samples tested at room temperature has been shown in Figures 3 to Figure 5 at different deformation speeds of 50 °/min, 100°/min and 500 °/min respectively.

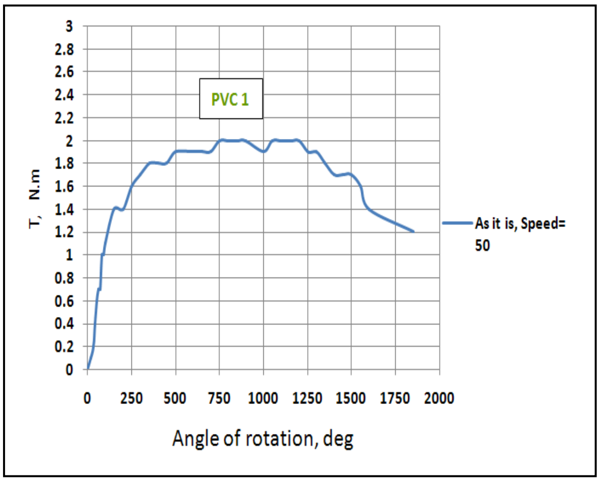

Figure 3 Torque- angle of rotation curve for as it is sample, speed=50°/min

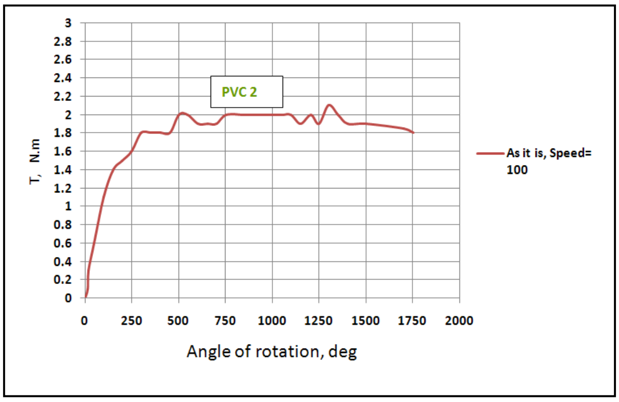

Figure 4 Torque- angle of rotation curve for as it is sample, speed= 100°/min

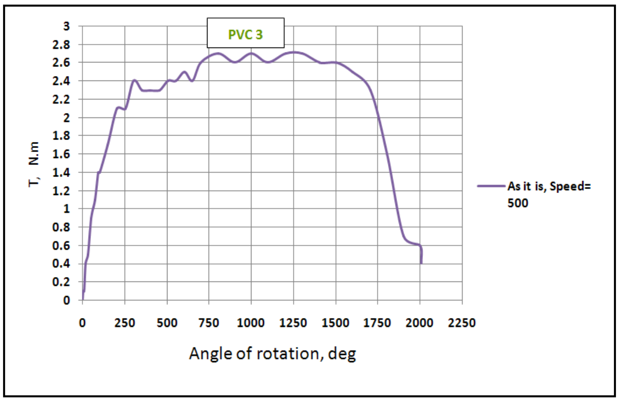

Figure 5 Torque- angle of rotation curve for as it is sample, speed= 500°/min

Figure 6 shows the comparison of the three samples PV1, PVC2 and PVC3 for the testing conditions explained in Table 1. It is clear from the figure that the maximum torque recorded was between 2 N.m to 2.7 N.m while the torque at sample rapture was between 0.4 N.m to 1.8 N.m. The comparison showed that with increasing the deformation speed, the torque required for rupture decreases to 0.4 N.m with a rotation angle of 2005°.

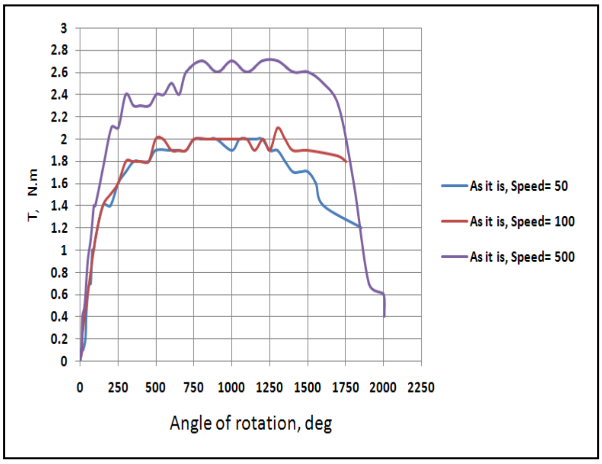

Figure 6 Comparison of as it is tested samples at different speeds

Through the above curves, it was found that for the tested samples at room temperature (as it is samples), the higher the speed of deformation accompany the maximum torque at peak points of the curves and minimum torque at rupture.
To show the effect of temperate change during the service of PVC, the prepared samples have been cooled at refrigerator to the available temperature given by the device. For this purpose two samples were tested at different deformation speeds.
For instance, Figure 7 gives the torque- angle of rotation curve for cooled sample to -18 °C at deformation speed of 100 °/min. Figure 8 shows the curve at deformation speed of 500 °/min.

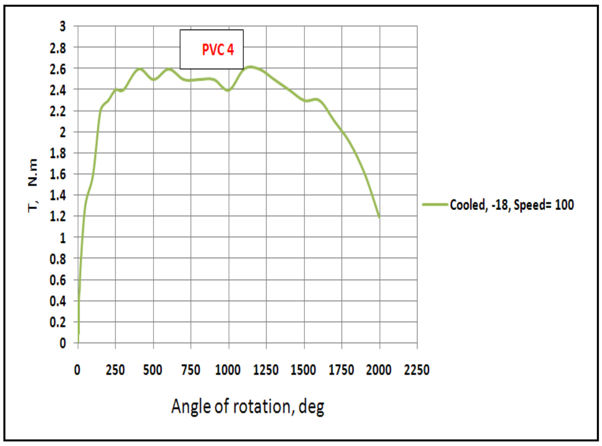

Figure 7 Torque- angle of rotation curve for cooled sample, speed=100°/min

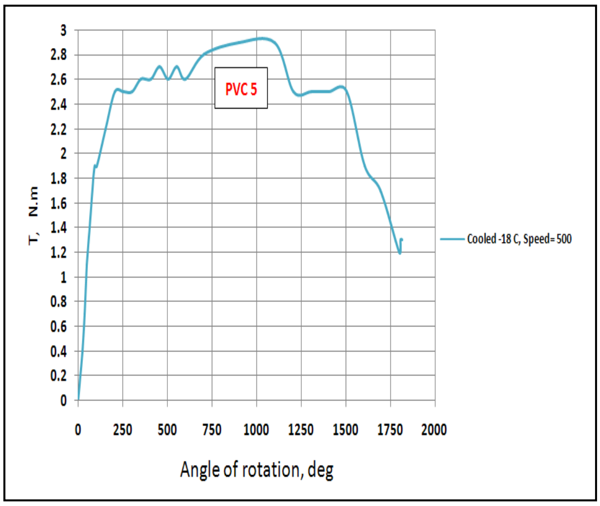

Figure 8 Torque- angle of rotation curve for cooled sample, speed=500°/min

The two curves show the maximum torque and torque at rupture with their angle of rotations. The maximum recorded torque was 2.9 N.m at 500 °/min with 1.2 N.m rupture torque at an angle of rotation of 1814°. The results for the two samples are combined in Figure 9 for comparison.

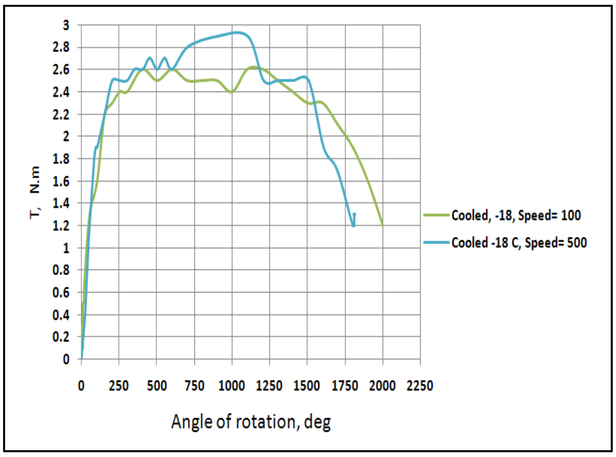

Figure 9 Comparison of tested cooled samples at different speeds

To show a clear view for the different testing conditions, all the tests are combined in Figure 10. From the figure, it can be obviously observed that the torque at peak point increases where the sample temperature decreases from room temperature to a particular cooling temperature (-18° C). The maximum torque range increases from 2 N.m to 2.9 N.m with less value of angle of rotation (1814° for cooling sample in compare to 2005° for as it is sample). This means that the cooling condition made the material harder and can resist a higher value of the applied torque.

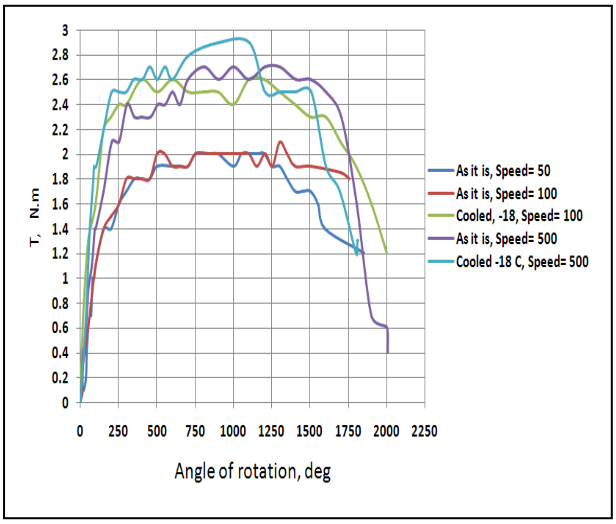

Figure 10 Comparison of tested samples at different testing temperature anddeformation speeds.

From the above curves one can also observe that the cooling of the PVC changes its mechanical properties and require a higher rapture torque where the value changes from 1.3 N.m for the cooled sample to 0.4 N.m for as it is sample.
The torsional fracture resistance (τ_b) for the tested samples is calculated by applying equations 1 to 3. The results are tabulated in Table 2 and shown in Figure 11. For the two tested groups of PVC, the results showed that

this torsional value decreases with an increase of deformation speed. For the first three tests 1, 2, and 3 the value for torsional resistance decreases from 10.191 MPa to 3.057 MPa. And for the cooled samples (tests number 4 and 5) this valve decreases from 8.152 MPa to 6.62 MPa. In comparing the value of samples tested at 500 °/min for both received and cooled (tests number 3 and 5 respectively), the value of torsional resistance increases from 3.057 MPa to 6.62 MPa. The result above is in compatible with the results given by the previously explained curves.

Table 2 Values of torsional fracture resistance for different testing conditions

Test No.	Test Condition	Deformation Speed	Torsional Fracture Resistance (τ_b) , MPa
1	As it is (received)	50 °/min	10.191
2	As it is (received)	100 °/min	7.133
3	As it is (received)	500 °/min	3.057
4	Cooled to -18 °C	100 °/min	8.152
5	Cooled to -18 °C	500 °/min	6.62

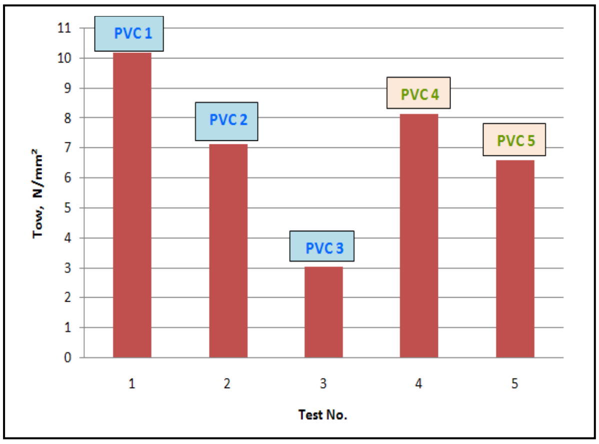

Figure 11 Torsional fracture resistances for the tested samples

Lastly the shear modulus has been found (Table 3 and Figure 12) by using equation 4. The G values increase from 140 MPa for as it is sample tested at deformation speed of 500 °/min (test no. 3) to 282 MPa for the cooled sample tested at the same condition (test no. 5). This gives more strength to the PVC material and enhances its usage and applications.

Table 3 Values of shear modulus for different testing conditions

Test No.	Test Condition	Deformation Speed	Shear Modulus G
1	As it is (received)	50 °/min	142 N/mm^2
2	As it is (received)	100 °/min	119 N/mm^2
3	As it is (received)	500 °/min	140 N/mm^2
4	Cooled to -18 °C	100 °/min	264 N/mm^2
5	Cooled to -18 °C	500 °/min	282 N/mm^2

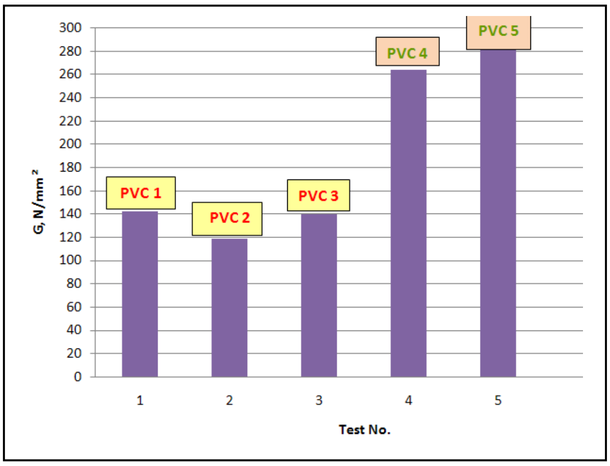

Figure 12 Shear modulus for the tested samples

4. CONCLUSION

Experimental tests conducted to show the torsional property of PVC available in the local market. Standard PVC samples were prepared using both lathe machine and vertical milling machine. A torsion testing apparatus used to apply torque until the fracture of the specimens. Deformation speeds of 50, 100, and 500°/min were applied. The samples were tested at different temperatures. The testing conditions were as follows:

- received samples at room temperate for speeds of 50, 100, and 500°/min.
- cooled samples to -18 °C at speed of 100 and 500°/min.

From the results, it can be concluded that:

(1) Changing of service temperature has a considerable effect on the properties of the tested polymer by making the material harder and can resist higher value of the applied torque (2.9 N.m for the cooled sample to 2 N.m for the received sample tested at room temperature).

(2) Continuing on the previous conclusion, the angle of rotation decreases for the case of cooled samples in

compare to the received samples (1814º for cooling sample compare to 2005º for as it is sample).

(3) As the deformation speed increases we need a higher torque for rapture, it becomes clear to us that the cooling of the PVC changes its mechanical properties and requires a higher rapture torque (1.3 N.m for cooled sample to 0.4 for as it is sample).

(4) The shear modulus, G, values increase with the temperature change. The value increases from 140 MPa for the as it is sample tested at deformation speed of 500 °/min to 282 MPa for the cooled sample tested at the same condition. This means that the cooling conditions give more strength to the PVC material and enhances its usage and applications.

(5) For the two tested groups of PVC the results showed that the torsional resistance value decreases with an increase of deformation speed. At the same time the value of torsional resistance increases from 3.057 MPa to 6.62 MPa when the sample had been cooled.

The above results and conclusions give a guideline for designers of how to use parts made of PVC in different applications where the range of both the maximum torque and failure torque with their mechanical properties of rigidity and torsional resistance were recorded.The current work can be expanded in several directions. The experiments can be expanded by conducting other tests such us fatigue and impact and utilizing other types of polymers for comparison.

5. REFERENCES

[1] P.C. Sugumaran, "Experimentalstudy on dielectric and mechanical properties of PVC cable insulation with Sio_2/$Caco_3$nano fillers", IEEE Annual Report Conference on Electrical Insulation and Dialectic Phenomena, pp. 503-506, 2015.

[2] W. Bolten, Engineering Materials Technology, Third edition, 1998.

[3] Polyvinylchloride (PVC)[Online].Available: http://www.pvc.org/en. [Accessed: March10, 2017].

[4] Y. Kemari, A.Mekhaldi, M.Teguar, "Investigationintothedissipatedenergyunderacceleratedthermalaging in PVC/B used in lowvoltage cables insulation",pp. 1-4, IEEE 2016.

[5] C. Sunanda, M.N.Dinesh, N.Vasudev, "Performance evaluation of silicon rubber insulating material with MgOandZnOnano fillers", pp. 1-5, IEEE 2016.

[6] I. K. Bishay, S.L. Abd-El-Messieh, S.H. Mansour, "Electrical, mechanical and thermal properties of polyvinyl chloride composites filled with aluminum powder", Journal of Materials& Design, 32(1), pp. 62-68, 2011.

[7] H. Wang, G.Xie, M.Fang, Z.Ying, Y.Tong, Y. Zeng, "Electrical and mechanical properties of antistatic PVC films containing multi-layer graphene", Journal of Composites Part B 79, pp. 444-450, 2015.

[8] M. Colloca, G.Dorogokupets, N. Gupta, M. Porfiri,"Mechanical properties and failure mechanisms of closed cell PVC foams", International Journal of Crashworthiness, 17(3), pp. 327-336, 2012.

[9] A. Ashori, H. Kiani, S.A.Mozaffari, "Mechanical properties of reinforced PVC composites: effect of filler form and content", Journal of Applied Polymer Science, 120, pp. 1788-1793, 2011.

[10] F.C. Grozema, P.T. V. Duijnen, Y.A. Berlin, M. A. Ratner, L.D.A.Siebbeles, "Intra molecular charge transport along isolated chains of conjugated polymers: effect of torsional disorder and polymerization defects", Journal of Physics Chemistry B, 106, pp. 7791-7795, 2011.

[11] A. Ghobarah, M. N. Ghorbel, S. E. Chidiac, "Upgrading torsional resistance of reinforced concrete beams using fiber-reinforced polymer", Journal of Composites for Construction, 6(4), pp. 257-263, 2002.

[12] F. Povolo, G. Schwartz, E. B. Hermida, "Stress relaxation of PVC below the yield point", Journal of Polymer Science Part B: Polymer Physics, 34, pp. 1257-1267, 1996.

[13] Equipment for Engineering Education, GUNT Catalogue, Germany. Torsion Testing Machine, 200 Nm motor driven.