Towards an Efficient Electric Pole's Material for Iraqi Electric Network

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Abstract

The traditional electric poles in Iraq are usually made from steel materials. Such materials induced high weight, corrosion, permanent deformation caused by high wind speed, etc. The study aimed to numerically examine the strength of few poles made from different materials. The pole subjected to pressure developed by actual measured wind speed of 140 km/h. The numerical model of different materials and cross sections, an octagonal section electric pole made from composite material FRP–HDPE–FRP is suggested to replace the traditional one. The results showed high safety factor, approximately 5.51 besides the low ratio of high strength to weight as compared to steel materials. Using HDPE as reinforced material resulted in pole elastically deformed with only 0.222 mm. Therefore, it can be assumed that the suggested pole acts partially as a damper. Straight octagonal cross - section of pole promoted high reduction (74.22%) in maximum Von–Misses stress of that obtained in cylindrical three-stage pole. High reduction (5.87 times) in maximum deformation value was obtained when composite octagonal pole was used as compare to tapered pole made from steel.

Keywords: electric poles, finite element method, HDPE, FRP.

Nomenclature:

A = half surface area of pole (ft^2)
C_d = drag coefficient (dimensionless)
C_h = coefficient reflecting height and terrain effects (dimensionless)
D = pole diameter (m)
HDPE = High Density Polyethylene
L = pole length (m)
I = moment of inertia (m^4)
P = wind pressure on unit area (psf)
V = mean design wind speed (mph)
σ_b = bending stress (N/m^2)
ρ = density (kg/m^3)
μ = coefficient of fluid viscosity (m-sec/N)
ω = distributed load (N/m)

1 Introduction

The traditional pole made from steel in two cross – sectional types (circular three stages tapered and one stage tapered pole types) are failed when exposed to high wind speed. On other side, a structural composite performance and properties made to be superior to those of constituent materials acting independently in wide range of applications.

Recently, the fiber reinforced polymers (FRP) composite are successfully use to alter the steel material in structures of many applications [1, 2]. The FRP promotes high corrosion resistance, excellent mechanical properties, and high strength-to-weight ratio [3]. Different types of FRP poles, having different geometrical properties. FRP is made from two different types of glass fibers which are subjected to full scale flexural static testing [4]. For example, three pole structures on the roof top of the building for network coverage are made from steel and FRP simulate by imposing to dead load (self-weight and communication system weight) with addition to wind load, maximum stress appear in three poles using ANSYS software were 117.29 MPa and 37.228 MPa in steel and FRP structure respectively [5]. The experimental results show that the low linear density of glass - fibers provided an increase in ultimate load reach to 38 % for other FRP poles [6]. The three segment pole design improves the ultimate load and flexural stiffness with light weight. The FRP designs are conformed according to the minimum ultimate moment and the allowable maximum deflection as specified in the ASTM, ANSI and AASHTO LT S standards [7]. The pre-study was performed for a pole handle 220 KV electric wire, the pole's material made from fiber glass and polyester as matrix, the mechanical properties of composite were approximately twice than its matrix phase due to the existing of reinforcing fibers [8].

The ANSYS simulation results of FRP, tapered cross sectional pole subjected to wind load were 328.7 mm and 142.6 MPa as maximum deformation and maximum principal stress, respectively [9]. The drag force on cylinder is proportional to the cylinder diameter, and the drag coefficient due to applied wind pressure is distributed uniformly on half circumference of the cylinder [10]. The tapered transmission pole made from FRP is analyzed numerically using finite element method provided by "MATHMATICA" program. Major reduction in both stress and deformation are determined due to small decrease in tapered angle with constant diameter [11]. The octagonal poles were used when high wind speed is exerted on surface of pole as detailed in "IS 875 and verify requirements of standard BS: 5649 part VI 1982" [12].

In present study, a composite material made from three layers of FRP-HDPE-FRP was used to numerically simulate an octagonal cross section pole which exposed to pressure developed by maximum measured wind speed in specific area of Iraq.

2 Theory and case study

The static pressure coefficient is determined by the pressure different between atmosphere and pole surface in addition to air density and stream velocity [10] :

$$C_p = \frac{p - p_o}{\frac{1}{2}\rho\, v^2} \quad (1)$$

Integral of the pressure coefficient around pole surface yields to:

$$C_d = \int_0^{\pi} C_p \, d\theta \quad (2)$$

Single support pole of 9 m length as shown in Figure (1) is exposed to wind lateral pressures. The pressure is calculated from knowing wind velocity and drag coefficient as follow in (psi) unit [13] :

$$P = 0.00256 * (1.3 * V)^2 * A * C_d * C \quad (3)$$

Where, $A = \frac{\pi D L}{2}$

The constant in equation (0.00256) represent converts the kinetic energy of the air speed to potential energy of velocity pressure, while the constant (1.3) is modifies the wind velocity which in mph unit.

The drag coefficient is read from special chart depends on Reynolds number:

$$R_n = \frac{V D \rho}{\mu} \quad (4)$$

In current work, the velocity is taken 140 km/h (87 mph) and mean diameter of 114 mm for three different stages size of pole height, the Reynolds number is 0.289 X 10^6. The drag coefficient is 1.2.

The magnitude of pressure exposed to pole, after substitute R_n, V, C_d, and put C_h = 1, in equation (3) is 567 psf (27.15 KPa).

The thick and short column is failed by yield point, while the thin and long is "collapse" under the yielding. The collapse pressure or as called "critical pressure" for long tube under uniform radial external pressure is expressed as [14]:

$$P_{cr} = \frac{E}{1 - v^2} \left(\frac{t}{D}\right)^3 \quad (5)$$

Where, the first wave of buckling form of pole is taken into account only. There is no numerical or experimental formula for developed Von – Misses stresses exists due to exposing external pressure on pole.

The elementary flexural or bending stress developed in beam (pole) due to applied pressure and maximum deformation due to distributed load is:

$$\sigma_b = \frac{My}{I} \quad (6)$$

$$\delta = \frac{\omega L^4}{8EI} \quad (7)$$

By substituting $M = \frac{PAL}{2}$, the bending stress Eq (6) of pole under pressure can be as follow:

$$\sigma_b = \frac{PALy}{2I} \quad (8)$$

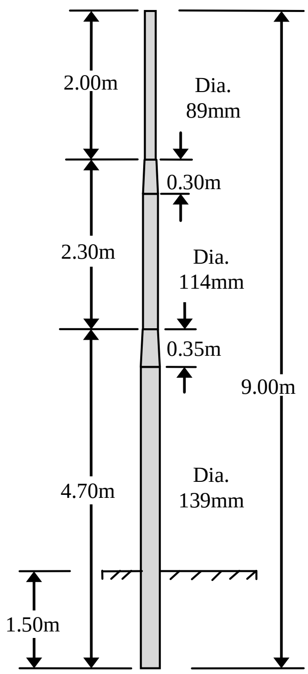


Figure 1: Three different cross section of 9 m pole length.

3 Methods

The flow chart of main investigations steps in current work is shown in Figure 2.

The pole specimen made from HDPE reinforced by grid of steel was produced in current work by using an isolated furnace which shown in Figure (3). The temperature was around 200 °C which is higher than melting temperature of HDPE. The specimen die is manufactured from steel consist of two parts fastened by screw in order to easy reject the specimen after complete the melting process as shown in Figure (4). Two types of reinforced steel grid are used (fine and coarse) with final form in specimens are obtained in Figure (5), each specimen has (70.44 g) and (8.4 x 5.4 x 1.3) cm, so the density of new material is 1.194 g/cm^3.

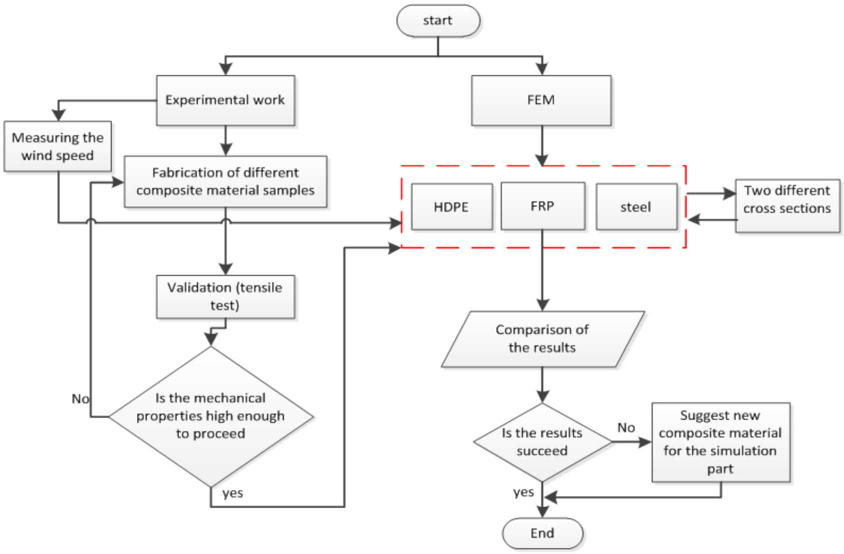
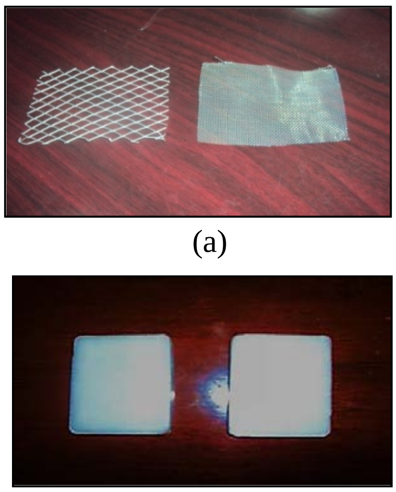


Figure 2: Flowchart explains the followed methodology.

Figure 3: Furnace for manufacturing the specimens.

Figure 4: The die used for manufacturing composite specimen.



(a)

(b)

Figure 5: Manufacturing of HDPE specimens, (a) Steel grids, (b) Final form of HDPE.

The HDPE mechanical properties could be changed with regard to temperature change. It is worthily to mention that the weather temperature of Iraq during summer season can reached to 50 $^{\circ}$C. However, it was found that there is no large difference in ultimate tensile strength and elongation for different temperatures. Figure (6) explains the claimed results by Merah et al., [15]. Besides, the researchers are going on in this field to find different types of HDPE with better mechanical properties and high temperature resistance through morphology structure [16].

The anemometer shown in Figure (7) was used to measure the wind speed. The test is carried out in west of Iraq to ensure measuring the maximum value in order to perform the sever boundary condition in numerical modeling of pole and so detect the failure.

The tensile tests of two specimens (fine and coarse steel grids) were carried out in Material and Production Department/University of Technology. The range of applied force for device

(WDW – 200 E) is limited between 0.04 – 200 kN, with jaws feeding speed of 1 mm/min. The specimen dimensions were cut according to ASTM standard [17].

The finite element method is applying in ANSYS PROGRAM using (Brick 8 – node 45) structural element which represent isometric element has 8 nodes four at corner of rectangular face and other on mid distances of boundary, after meshing the entire pole is divided into 3245 element including the base elements (made from concrete) as shown in Figure (8).

The Von - Misses yield criterion or as called "Maximum Distortion Energy Theory of Failure" is adopted in present work due to its high accuracy results as compare with other failure theories. The Von – Misses stress in three dimensional loading is,

$$\sigma_{von\text{-}Misses} = \sqrt{\frac{1}{2}}\,[(\sigma_{11} - \sigma_{22})^2 + (\sigma_{22} - \sigma_{33})^2 + (\sigma_{33} - \sigma_{11})^2 + 6\,(\tau^2_{23} + \tau^2_{31} + \tau_{12}^{\,2})] \qquad (9)$$

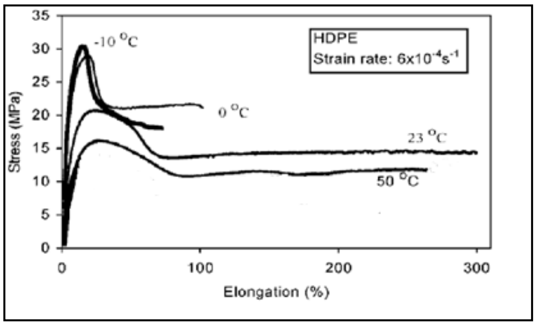
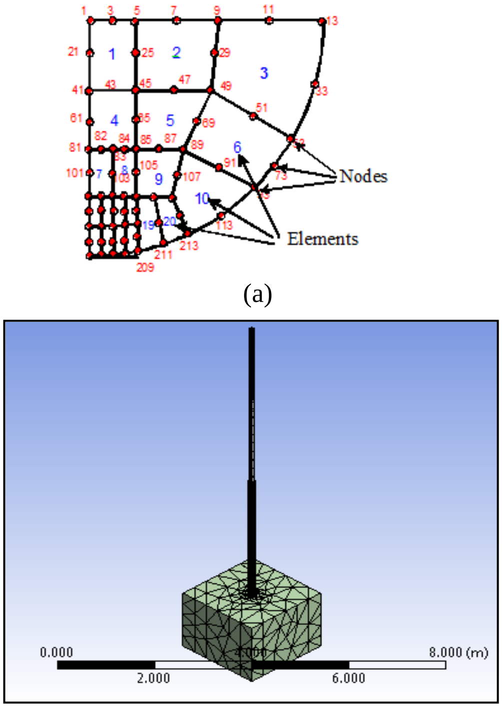


Figure 6: Effect of temperature on strength of HDPE [15].

Figure 7: Anemometer device to measure the wind speed.



(a)

(b)

Figure 8: Finite element of pole. (a) 8–node element, (b) entire pole after mesh

4 Results and Discussion

The maximum speed of wind is measured to be 140 km/h using. The fracture path of specimen is shown in Figure (9) after applied gradually load up to failure force of 180 N. The investigated mechanical properties are listed in Table (1) in comparison with steel and FRP material.

The numerical simulation of 9 m pole with dimension shown in Figure (1) is carried out by applying the pressure of 27.15 KPa along pole length as shown in Figure (10). For tapered one section design can be setting same pressure over entire length of pole in the form of cone with two diameters, 139 mm on bottom and 89 mm on top similar to three stage pole.

The bending deformations induced for two design of poles made from HDPE with coarse grid reinforced steel under study is shown in Figure (11), while developed Von – Misses stresses is seen in Figure (12).

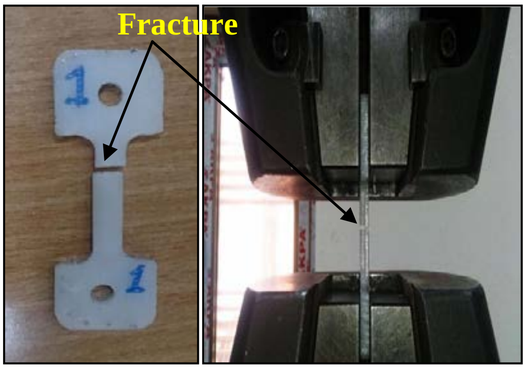
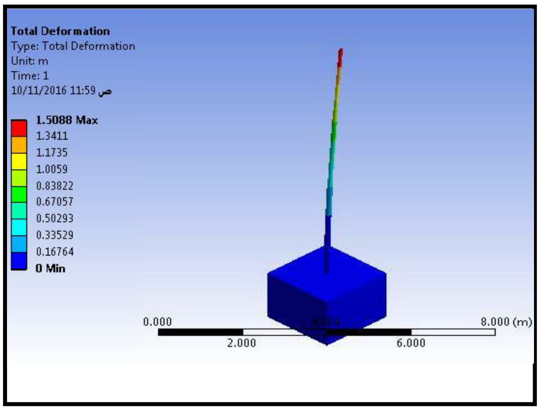


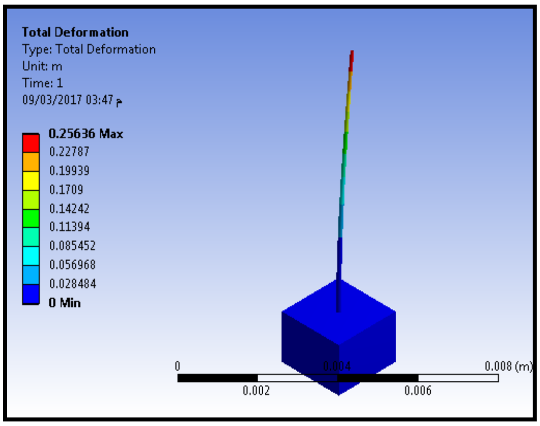
Figure 9: Fracture path of HDPE specimen caused by tensile test.

Table (1): Mechanical properties of steel, FRP, and HDPE.

No.	Material		E (GPa)	σ_y(MPa)	σ_u(MPa)
1	Steel [18]		200	250	450
2	FRP [18](S – glass)		85	538	880
3	HDPE	fine	503	5.03	13.59
		coarse	1016	5.08	16.14



(a)



(b)

Figure 11: Deformation of pole in (m). (a) three sections, , (b) one taper section.

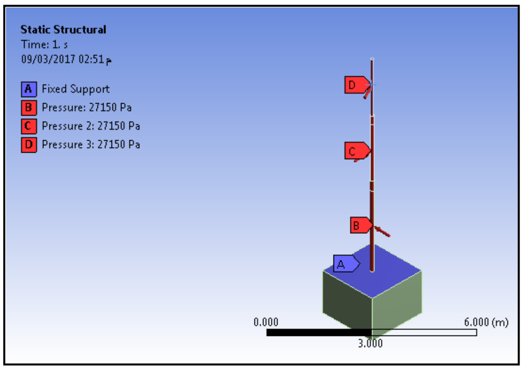
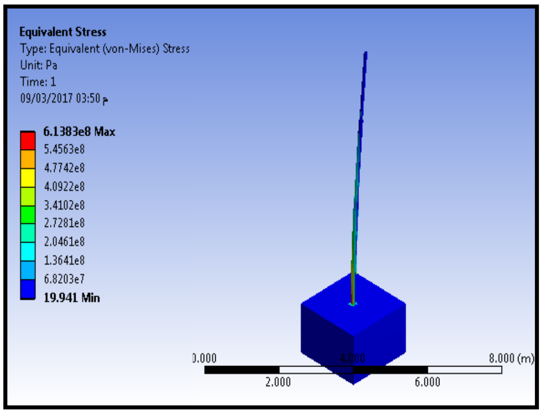
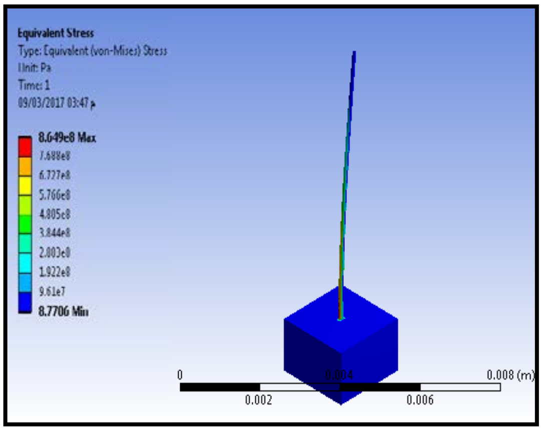


Figure 10: Application of loading and support of three – sections pole.



(a)



(b)

Figure 12: Von – Misses stress in pole in (Pa). (a) three sections, (b) one taper section.

The composite material of pole made from three layers (FRP–HDPE–FRP) in octagonal 8 – faces cross – sectional area is shown in Figure (13). The outside and inside diameters of octagonal are 120 and 90 mm respectively, with equal layers thickness of 5 mm for each layer. As the composite pole is symmetric, so one of eight faces is draw in ANSYS (42.1 mm) less than one to third of pressure magnitude is applied along

0.25 m from bottom. The deformation developed in composite material is show in Figure (14).

The Von – Misses stresses induced on pole along its length from base are depicted in Figure (15). The graph of stress versus length of pole is shown in Figure (16). Stress variation across the thickness (layers) is seen in Figure (17). A comparison between current work and other investigation can be shown through Figure (18) which explains the stresses distribution on one face of octagonal cross–section with similar regions of stress concentration at boundary of pole root are developed.

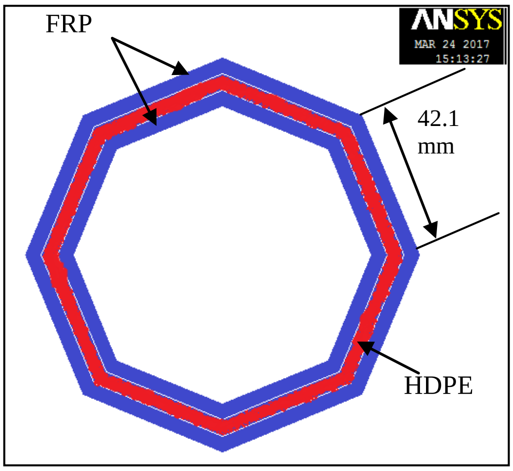


Figure 13: Octagonal cross – sectional area of pole.

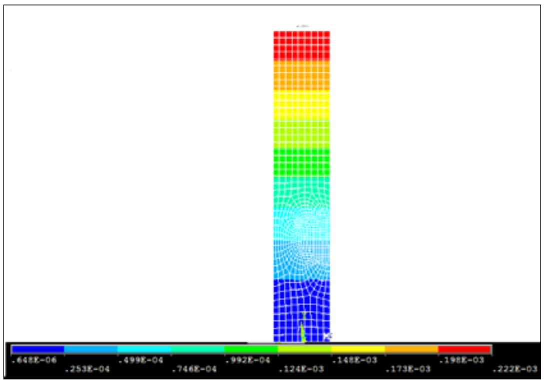


Figure 14: Deformation of composite material (m).

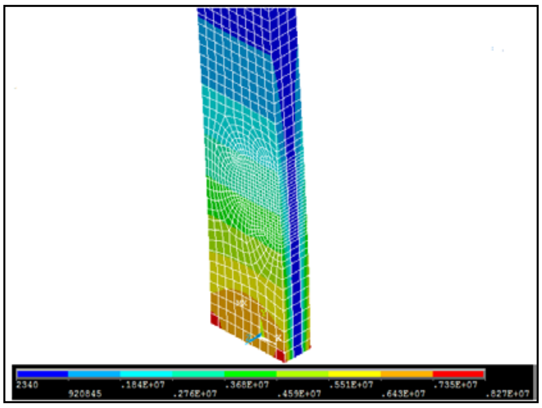


Figure 15: Von – Misses stress along 0.25 m from base (N/m^2).

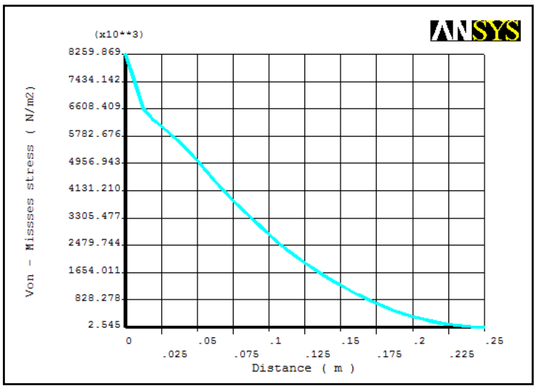


Figure 16: Von – Misses variation across 0.25 m from base (N / m^2).

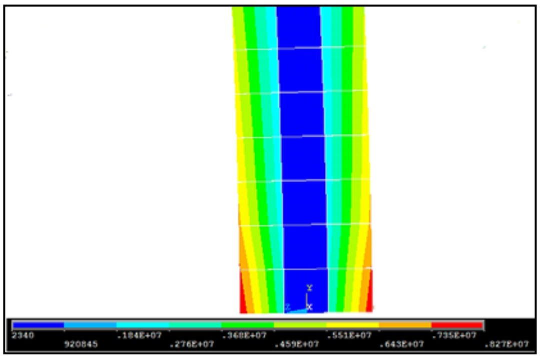


Figure 17: Von – Misses stress across thickness (N / m^2).

The strength to weight ratio for steel, FRP, HDPE, and composite material are estimated and listed as columns shape in Figure (19), strength of each material is represented by yielding limit.

The numerical results of deformations and stresses for all tested materials with different cross–sectional area were considered in current work determined and collected in Table (2).

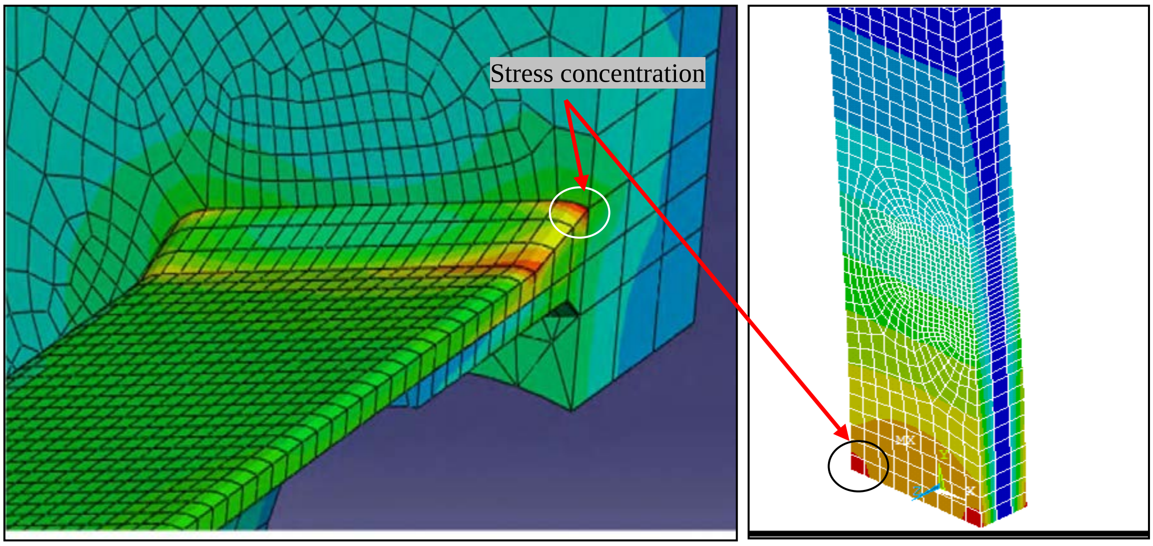


Figure 18: Stress concentration regions, (a) Results from ref [19], (b) Results of current work

Table (2): Numerical results (FEM).

No.	Material	Pole	Von – Misses stress (MPa)	Deformation (m)
1	Steel	One section Taper	865	0.001303
		Three section straight	613.8	0.641
		Octagonal section	8.26	0.432
2	FRP (S – glass)	One section Taper	865	0.00306
		Three section straight	613.8	0.8641
		Octagonal section	8.26	0.598
3	HDPE	One section Taper	865	0.25636
		Three section straight	613.8	1.509
		Octagonal section	8.26	0.9456
4	Composite FRP – HDPE - FRP	One section Taper	865	0.004567
		Three section straight	613.8	0.01236
		Octagonal section	8.26	0.000222

So far, the obtained results are generally agreed the available results in many references [1, 5, 13] for different materials and composites. In current work, both experimental and numerical investigations were carried out. The experiment results are measured the maximum speed of wind in open environment to about 140 km/h, this value is substituted to empirical equation of pressure in order to estimate maximum value of pressure exposed to 9 m polenamely 27150 KPa. Secondly, the manufacturing of HDPE specimens reinforced by two types of steel grid (fine and coarse) were tested to evaluate its mechanical properties which shown in Table (1) together with mechanical properties of steel and FRP.

In numerical investigation, the three materials Steel, FRP, and coarse HDPE (due to its higher strength than fine) are used as pole material individually by applying the maximum pressure on rounded three stage pole and taper pole. The final results including the deformation and Von – Misses stress are determined using ANSYS PACKAGE and collected in Table (2).

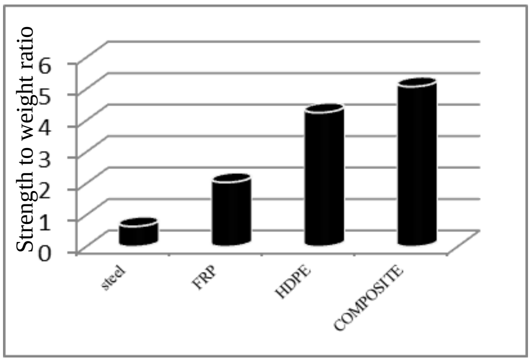


Figure 19: Strength to weight ratio

Table (2) are showed all materials failed (except composite material) by exceeding its yield stress. The tapered pole for all cases gives higher stresses with lower deformation when compared with three stage ordinary pole. The Von – Misses stress is the same for all material namely 613.8 and 865 MPa for three stage and one stage pole respectively, this due to the stress formula (equation 8) depends on applied load and cross – sectional area only and do not respect to material.

The deformations of three materials are 0.001303, 0.00306, and 0.25636 m for steel, FRP and coarse HDPE respectively for tapered pole are greatly lower than against values for same material but for three stage pole. The tapered pole gives good deformation but higher stresses that exceeding the design limits, so the three types of materials individually are failed. The octagonal cross – sections is safe design according to stress in steel, FRP, and HDPE but with high deformations 0.432, 0.598, and 0.9456 m respectively that exceed the design limits.

The composite material is the solution, by combining the strong property of FRP and high elasticity of HDEP. The deformation and bending stress are both depends to moment of inertia as clearly shown in equations (7) and (8), higher moment of inertia (depends on cross – section area) means lower stress and deformation.

Three layers are used in current work each of 5 mm exposedone face(42.1 mm) of octagonal to 9050 Pa due to symmetry of design. New design and composite is gives wonderful results which below yield point.

The maximum deformation was 0.222 m (Figure 13) less than that obtained from tapered pole made from steel, approximately 1.303 mm, as explained in Table (2) by 5.87 times, while maximum Von – Misses developed at root of pole Figure (14) is 8.27 MPa is less with so big difference than 613.8 MPa in three – stage pole with 74.22 times and then more safe design is obtained. Figure (15) is shows variation of stress from maximum value at root to minimum at quarter of meter from base namely 2.545 KPa.

The intermediate material (HDPE) shown in Figure (16) could developed lower stress than FRP regions (blue color) reach to 0.921 MPa which far lower than yield stress of 5.08 MPa with safety factor of 5.51. The minimum stress at HDPE region is proved the idea of elasticity of material make it like pad between two strong wall minimize the overall stresses in the pole.

The strength to weight ratio present the composite materials is the best one among other materials by 5.080 Mpa.cm^3/g which higher than against values of HDPE, FRP and steel by 19.3 %, 49.0 %, and 7.9 times respectively.

The composite materials is more stronger material which withstand high wind speed, while HDPE is more elastic material with higher deformation against other materials and lighter in weight (only 1194 kg/m^3), while FRP more tough (without yield point) and moderate light weight (2490 kg/m^3).

Finally, the HDPE is make pole bend elastically if car or vehicle is strike it, where the shock developed is damped quickly that cannot reach to this phenomena by other tough materials. It can be assumed that the elastic material behaves absorb the applied forces and the pole work as "damper".

5 Conclusions

The major points which concluded from the current work, can be listed as follows:

1- Using composite material FRP – HDPE – FRP with octagonal cross-sectional pole of 9 m length is safely bend under pressure that developed by wind velocity reached to 140 km/h.
2- High strength to weight ratio is obtained from using octagonal composite material pole reached to 19.3%, 49.0%, and 7.9 times against rounded or tapered poles made from HDPE, FRP, and steel respectively.
3- Maximum deformation in pole of composite material is only 0.222 mm lower about 5.87 times than against value for all individual material including the steel.
4- Factor of safety for HDPE in intermediate layer is 5.51 leave more reduction of stress in adjacent layers, and more safe in design is achieved by making the pole structure bend elastically under wind or accident of car performing as "damper".

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نحو استعمال مواد هندسية كفوءة لأعمدة الكهرباء المستخدمة في شبكة العراق

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الجامعة التقنية الوسطى

الخلاصة

عادة ما يصنع عمود نقل الطاقة الكهربائية التقليدي في العراق من مواد الفولاذ. ان استخدام مثل هذه المواد الهندسية يتسبب في زيادة الوزن والتآكل الكيميائي والتشوه الدائم الناجم عن سرعة الرياح العالية، وما إلى ذلك. يهدف البحث الى تغيير مادة العمود التقليدي المستخدم حاليا والمصنوع من الفولاذ بمواد هندسية اخرى. يتعرض العمود للضغوط الناتجة عن سرعة الرياح المقاسة عمليا والتي كانت بحدود 140 كم/ساعة. بعد عدة محاولات لمحاكاة العددية لمواد مختلفة وبمقاطع رضية مختلفة ايضا, أقترح البحث الحالي استخدام نموذج لعمود نقل الطاقة الكهربائية مثمن المقطع مصنوع من مادة مركبة وهي FRP-HDPE-FRP كبديل عن العمود التقليدي الحالي. حيث أظهرت النتائج وجود عامل أمان عالي يصل حوالي الى 5.51، إلى جانب الوزن الخفيف والمتانة العالية لنسبة الوزن مقارنة بالصلب. أن استخدام HDPE كمادة قد عززت من مرونة العمود بتشوه يصل فقط الى 0.222 ملم. لذلك, يمكن افتراض أنه العمود المقترح يعمل بصورة جزئية كمخمد. ان المقطع العرضي للعمود على شكل مثمن يقلص الاجهاد الأقصى وفق معيار فون– مايسز بنسبة 74.22% بالمقارنة مع العمود الاسطواني المكون من ثلاثة مراحل. نسبة الانخفاض في اعلى تشوه حاصل كانت كبيرة جدا (5.87 اضعاف) عند استخدام عمود ذو مقطع مثمن مصنوع من المادة المركبة مقارنة مع العمود المسلوب المصنوع من الصلب ايضا.