Journal of Engineering and Sustainable Development
www.jeasd.org
Vol. 21, No.04, July 2017
ISSN 2520-0917

EFFECT OF ADDING NANO – POWDER ON COMPOSITE PIPES BEHAVIOR SUBJECTED TO MULTI STRESSES

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Abstract: This paper presents numerical, analytical and experimental studies of composite system for the Nano composite pipe. Woven roving and roving (fiber glass and carbon) composite pipes with (2%) Carbon Nano powder /epoxy composite and (50%) volume fraction have been tested. The experimental work included manufacturing pipe specimens by two techniques; first was filament winding technique using roving materials and second was vacuum bag technique which used woven roving materials. Also filament device was designed and manufactured. Manufacturing of composite pipes has been done as a conventional pipe for inner diameter of (100mm) and wall thickness of (4mm). In numerical work: the ANSYS package version (11) with element shell (63) was applied to investigate the effect of internal pressure on composite pipes. Test rig was designed and perform to study the effects of internal pressure and bending load on composite pipes, as well as the tensile test was done for the specimens. In analytical solution expression was achieved to define the effects of combined stresses on composite pipes.

Keywords: *Composite Pipes, Nano, Multi , Stresses*

تاثير اضافة مسحوق النانو على سلوك الانابيب المركبه موضوعه تحت تاثير اجهادات متعدده

الخلاصة: يمثل هذا العمل دراسة الجانب التحليلي ,العددي والعملي للانابيب المركبه بدون ومع اضافة النانو .لقد تم اختبار الانابيب المركبه المصنعه من الالياف الخيطيه والمحاكه (الزجاجيه والكاربونيه) مع اضافة نسبة (2%) من مسحوق النانو كربون /ايبوكسي وبنسبه حجميه مقدارها (50%) .يتضمن الجانب العملي تصنيع عينات الانابيب بتقنيتين احدهما تقنية لف الخيوط باستخدام الالياف الخيطيه والثانيه تقنية سحب الهواء باستخدام الالياف المحاكه . كذلك تم تصنيع الانابيب المركبه بالشكل التقليدي بقطر داخلي مقداره (100 ملم) وسمك مقداره (4 ملم) . اما في الجانب التحليلي تم استخدام ANSYS ,Version 11,Shell 63. وذلك لبيان تأثير الضغط الداخلي على الانابيب المركبه . تصميم وبناء منظومة الاختبارلدراسة تأثير الضغط الداخلي وحمل الانحناء على الانابيب المركبه كان من اهم فقرات الجانب العملي ,كذلك تم عمل اختبارات الشد لجميع العينات .اما في الجانب العددي فقد تم ايجاد صيغه لبيان تأثير الاجهادات المركبه الناتجه من الضغط الداخلي وحمل الانحناء معا" على الانابيب المركبه.

1. Introduction

New industries designs do not tolerate heavy metal pipes and prefer plastic replacements .Many applications of composite pipes are increasing tremendously along with the knowledge generation [1]. Composites pipes have become attractive for

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applications in oil gas, piping system, chemical industry, water treatment marine system and others. In the last two decades it has been widely proven that the mechanical properties (such as elastic modulus, strength) of various polymeric matrices can be remarkably improved through the addition of very small amounts (less than 5%) of nanostructured fillers [2]. In order to define nanometer scale items (10-9) the term Nano is used. The nanometer range covers sizes smaller than the wavelength range of visible light but bigger than several atoms, so addition of small amounts of nanoparticles to polymers has been able to enable new properties for the composite material [3].
Nano composites have been developed with nanoparticles incorporated into the matrix, high abrasion resistance can be obtained to promote good adhesion to different substrates, like metals, ceramics and plastics.

The addition of nanoparticles, especially in combination with epoxy, which act as an inorganic as well as an organic crosslinking agent, has been leads to a substantial increase of the abrasion resistance of such systems without losing any transparency [4].

Anisotropic characteristics of Nano composite piping provide extraordinary burst and collapse pressure ratings, increased tensile and compressive strengths, and increased load carrying capacities, Corrosion resistant and damage tolerant. Meets or exceeds published and consensus standards for pipeline in oil and gas applications [5],[6].

Pinar Karpuz [7] studied the mechanical characterization of filament wound composite tubes working under internal pressure load. Stratis Kanarachos and George Demosthenous [8] studied the mechanical behavior of composite metal plastic pipes subject to internal pressure and external soil and traffic loads. Guillermo Ramirez, et. al. [9] studied the external pressure testing of a large – scale composite pipe.
Prashanth Ramachandran [10] studied the experimental and numerical modeling of stresses in non – conventional cross sectioned composite pipes. Mohd Shukry Bin Abdul Majid [11] studied the behavior of filament wound glass fiber reinforced epoxy (GRE) composite pipes under hydrostatic and biaxial load conditions at temperature up to (95C). Peng Shang et.al. [12] studied the mechanical property analysis of two kinds of steel wire reinforced composite pipes. Nimish Kurien Thomas, et.al.[13] Focused on the stress analysis of Glass Reinforced Polymer (GRP) pipes subjected to internal and external loading. Al Sharif [14] found the design model of damaged steel pipes for Oil and Gas Industry using Composite Materials. In this paper, focus on the study of the behavior of composite pipelines made from (fiber glass, Nano-fiberglass, carbon and Nano-fiber Carbon) manufactured in two ways winding filament and winding mat, also studying a simple method for the manufacture of these two types of manufacturing methods in the laboratory and a detailed explanation of the behavior of these pipes under the influence of multi stresses. As well as will use combined stresses which it is (internal pressure stress and bending stress).

2. Experimental Work

The manufacturing of filament winder device to wind roving fibers has been done, and then the manufacturing of the test specimens by two methods has been carried out .The first by filament winding and the second by vacuum bag method. Preparation of the experimental rig was the most important part of this work by providing all the equipment for this purpose. The test rig was developed so that it is capable of performing test under various combinations of internal pressure (pure axial and pure hoop) then applying an external load as a bending moment. As well as this work include manufacturing tensile test specimens and an examination by tensile device.

2.1. *Manufacturing of Pipe Specimen*

Filament winding process and vacuum bagging are the most common techniques which used in this study:

2.1.1. *Filament Winding*

Figure (1) shows a basic filament winding process. A fiber roving is pulled from a series of creel. Tensioning is applied to the fibers while they are pulled from the creels, in order to get better wetting of fibers by the resin. At the end of the resin container, the roving is pulled through a wiping device where the excess resin is removed from the roving. After the appropriate number of layers has been applied, curing is carried out in an oven or at room temperature, after which the mandrel is removed [6].

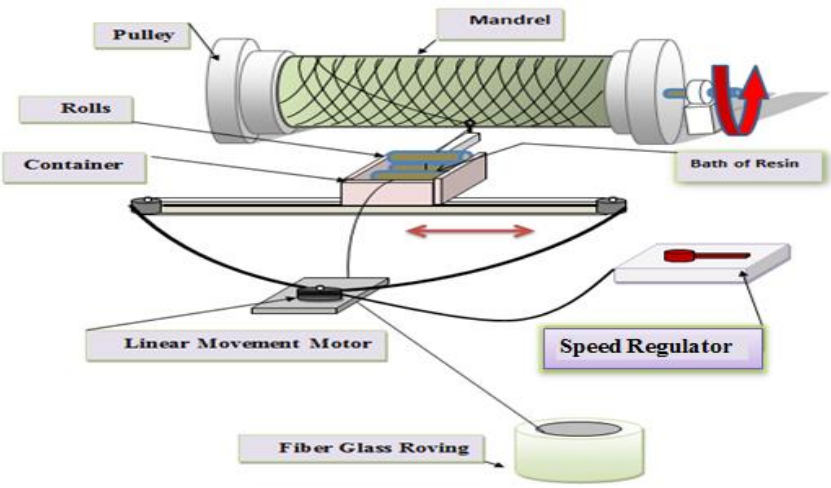


Figure (1): Basic filament winding process

2.1.1.1. *Filament Winder*

The filament winder is a machine that has been special technique designed to manufacture pipes with cylinder cross-sections. All the manufacturing processes were been conducting at especially mechanical workshop .The winder consists of many important parts as it shown in figure (2) and figure (3):

1.Mandrel: mandrel is rotating with speed spin, The arrangement of the fibers and the winding angle can be easily controlled for specific designs by coordinating mandrel rotation and carriage speed in order to obtain the required axial and hoop properties.

2. Resin Bath: The used resin bath is an epoxy with its hardener which is stored in rectangle plastic container consists of three rollers which it fixed on the carriage unit.

3. Carriage Unit: The carriage unit is responsible for feeding the fibers onto the mandrel traveling back and forth along the length of the mandrel.
4. Mandrel Support: It consisted of two cones with a space in between them to hold the mandrel.
5. Speed Regulator: The device was supported with two direct control motors, one to govern the rotating movement of the mandrel and the other one to control the linear motion of the carriage unit.

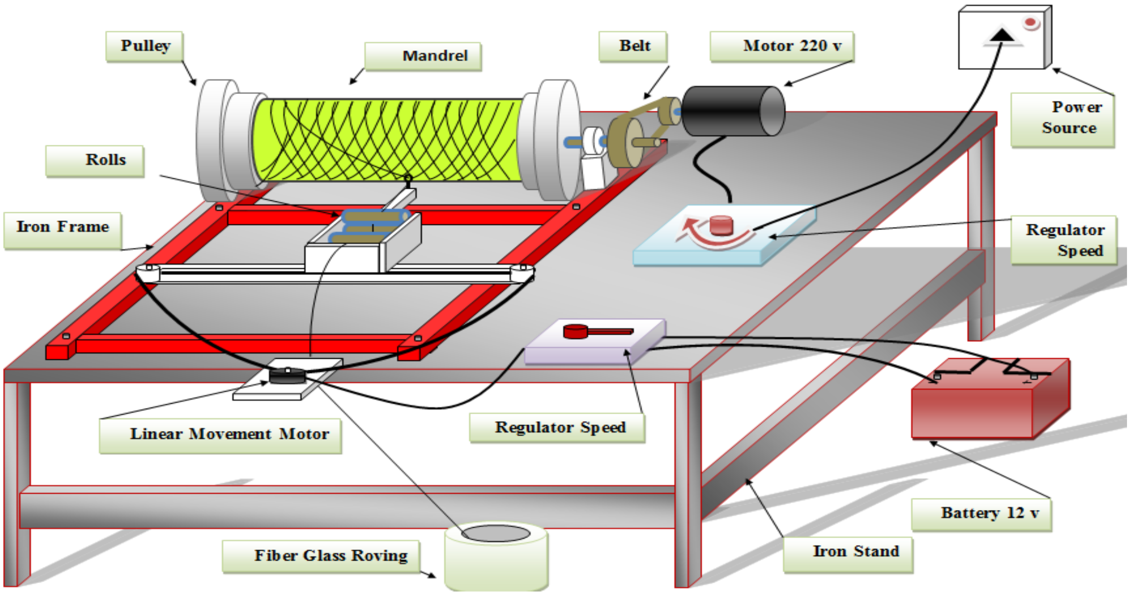


Figure (2): Schematic diagram of the filament winder

Figure (3): The filament winder

2.1.2. *Vacuum Bag Technique*

This technique is used for woven roving fiber material (Mat). When using vacuum bagging it causes the pressure inside the bag to reduce and the external pressure to increase, this will remove any excess air and resin and avoid us the existence of any defects resulting from aerobic bubbles. This technique consists of basic parts which it works full turn with each other as follows: gypsum mold, two PVA bag, vacuum device and different types of tubes, forming and cuttings as shown in figure (4).

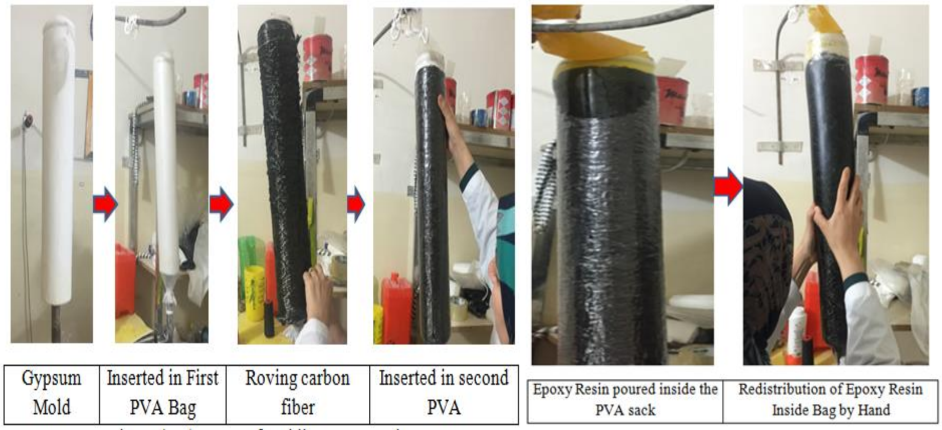


Figure (4): Steps of molding process pipe

2.2. End Fittings Design

For the research tests, which involved the pressurization of the specimen pipes, it was imperative to design an end-fitting suitable for the task. With such a (closed end) test setup, the axial load caused by the internal pressure is transferred to the pipe wall through the end fitting. Hence, a strong joint between the pipe end and the fittings is essential, so two end fittings were designed for the test setup. The design of both, adhesive bonded and mechanical end fittings are shown in figure (5).

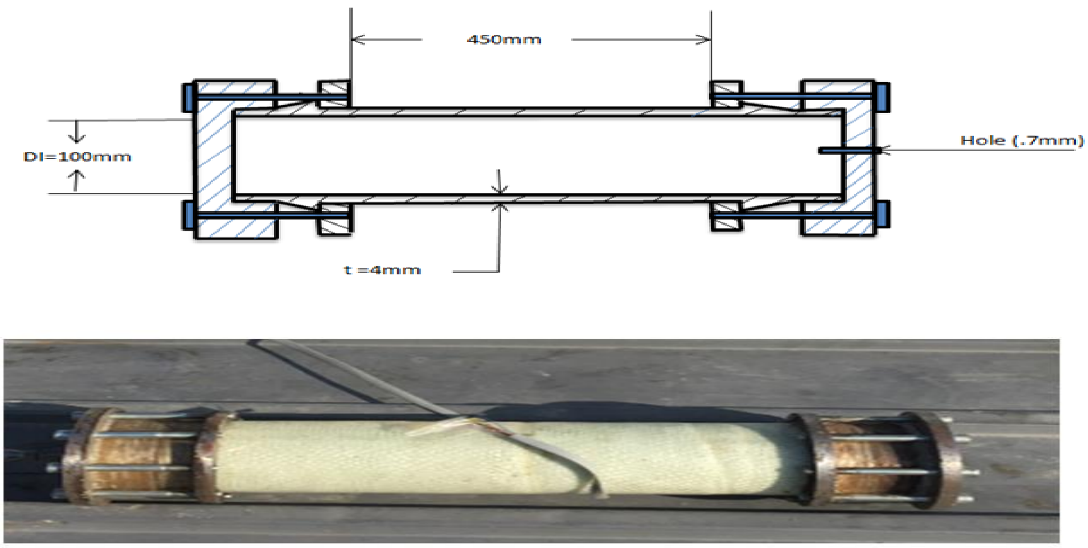


Figure (5): Design of mechanical end fitting

2.3. Developments Test Rig

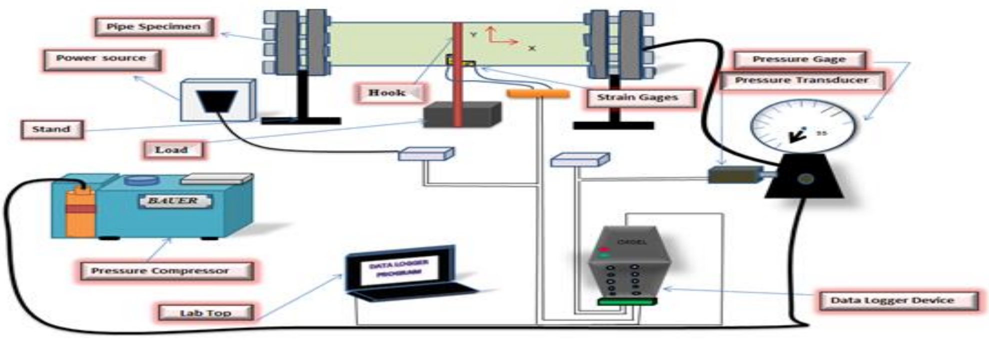
The tests conducted by applying internal pressure alone, giving hoop to axial ratio. In principle, the multi stress of composite pipes can be achieved by pressurizing the specimens to pressure less than yield point under a combination of tensile axial force and internal pressure. The test rig basically consists of four main parts:

A-The pressure system: Air Compressor Pressure, Transducer which is a sensitive device that contains a pressure differential circuit which constantly transmits the pressure reading inside the cylinder and Pressure Gauge to measure the internal pressure

B-Data Acquisition System Details: Digital Universal Data Logger which recorded the incident reflected and transmitted pulses versus time; also it is connected to the computer to view the reading in each test, Strain Gage set-up is a device whose electrical resistance varies proportionally to the change of strain.

C- Necessary Equipment: Pressure Hoses, Video System to connecting between the air compressor and the specimen and monitoring the process.

D- Bending system: as shown in figure (6): consist of hook and loads.



(a)

(b)

(c)

Figure (6): (a): Schematic Test Rig
(b): Test Rig with Internal Pressure only
(c): Test Rig with Internal Pressure and Bending

2.4. Experimental Procedures

The internal pressure test experimentation was carried out in the following sequence:
1. Cut specimens into desired length.
2. Fix the end closures by means of an adhesive and mechanical method.
3. The cables originated from the connecting terminals of the data acquisition system are connected to the strain gauges by soldering.
4. The specimen is connected to the pressure system.
5. Pressure is applied and increased uniformly and continuously, when the test ends, the pressure drops to zero and recording of elongation data is ended. Meanwhile, the pressure and elongation data is recorded as well from instruments below:
A- (Data Logger) device which transmit the variables in pressure and elongation to the computer.
B- Pressure transducer which transmit the variable of pressure to signals sense it the computer.
6. By the end of the test, the pressure and strain gauge data are studied in order to obtain the desired mechanical parameters.
7. The readings of the computer program would be in (mA)
8. The stresses values are evaluated from equations (3), (4) and (7).

3. Analytical Work

Theoretical consideration and definitions of the composite pipe under stresses are presented. The stresses and strains of cylindrical shell and pressure vessels were used in analysis transfer composite pipe. The hydrostatic pressure causes stresses in three dimensions , Longitudinal stress(axial) σ_L, Radial stress (σr) and hoop stress (σ_H) [15] .σr varies from P on inner surface to 0 on the outer surface ,so neglect (σr) .So the maximum stress will be calculated by using Von Mises stress theory.Also, the hoop and longitudinal strain terms can be obtained from the analytical and experimental data.The relations between the components of stress and the components of strain have been established experimentally and obeying Hooke's law [16].The equations used to estimate the strain for thin cylinders made of composite materials [12]:

$$\varepsilon_H=\sigma_H/E_H - \nu_{LH}.\sigma_L/E_L \longrightarrow \varepsilon_H=\sigma_H/E_1 - \nu_{21}.\sigma_L/E_2 \quad (1)$$

$$\varepsilon_L=\sigma_L/E_L - \nu_{HL}.\sigma_H/E_H \longrightarrow \varepsilon_L=\sigma_L/E_2 - \nu_{12}.\sigma_H/E_1 \quad (2)$$

Stresses should be found in term of strain because of the results which obtained from the experimental work, so equations (1) and (2) were used as below:

$$\sigma_L=\frac{E_2}{(1-\nu_{12}.\nu_{21})}.[\varepsilon_H.\nu_{12}+\varepsilon_L] \quad (3)$$

$$\sigma_H=\frac{E_1}{(1-\nu_{12}.\nu_{21})}.[\varepsilon_H+\varepsilon_L.\nu_{21}] \quad (4)$$

If an element initially unstressed and subjected to a constant Bending Moment along its length:

$$\sigma_B = \frac{M}{I} . y_{max} \quad (5)$$

Typical stress distribution in pipe specimens consists of internal pressure and bending moment, it is evident that the material near the N.A. is always subjected to restively low stresses compared with the areas most removed from the axis. In order to obtain the maximum resistance to bending it is advisable therefore to use sections which have large areas as far away from the N.A. as possible [17].

$$\sigma_{LB} = \sigma_L + \sigma_B \quad (6)$$

$$\sigma_{Von} = \sqrt{(\sigma_H)^2 + (\sigma_{LB})^2 - \sigma_H \ . \sigma_{LB}} \quad (7)$$

Where: (σ_B) is stress obtained from bending only and (σ_{LB}) is stress obtained from bending and internal pressure together.

4. Numerical Work

ANSYS package version (11) with element shell (63) was applied to investigate the effect of internal pressure on composite pipes is used for the stress and strain. Separate (once Fiber Glass and other carbon) in both cases (Mat and union roving) and adding Nano carbon powder. The numbers of elements used for this work model are (15019), while the number of nodes is (26881), as shown in figure (7).

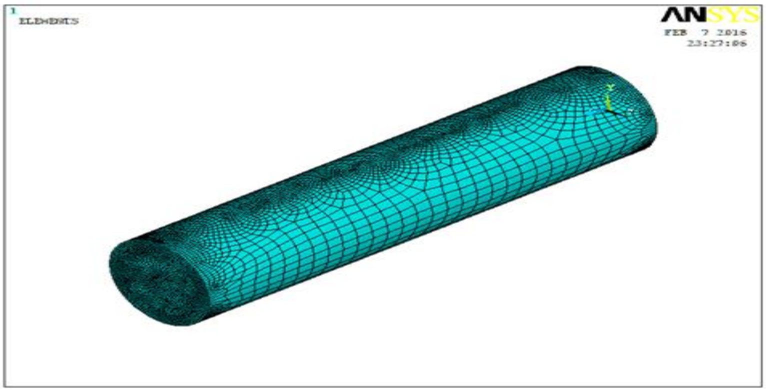


Figure (7): Pipe meshing

5. Materials Specifications

The materials of specimens including woven roving (Mat) and roving (Union) glass and carbon fiber at (4mm) thickness .Carbon Nanotubes (CNTs) are a tube –shaped material, made of carbon nanotubes (CNTs). Adding CNTs into polymers at very low weight fractions can improve mechanical properties of the resulting Nano composites, the results of mechanical tests (tensile and flexural) exhibit improvements of tensile and flexural strengths.in this study adding 2% of the resin mixture as shown in figure (8).

Figure (8): Adding the mixture of CNTs, resin and hardener from the hole above molding.

6. Results and Discussion

Figure (9) shows the effects of increasing pressure on the longitudinal and hoop strain and stresses for woven roving (Mat) and roving (Union) with and without Nano fiber glass composite pipe [(G.M.4),(G.U.4),(G.M.N.4) and (G.U.N.4)] will be discussed .

It was conclude that the longitudinal strain (ε_L) for the roving composite pipe without Nano(G.U.4) was more than for the same material with adding Nano powder by almost (50%), also more than of woven roving composite pipe with and without Nano at a rate higher than previous ratio as shown in figure (9-a) , this result backing to the nature of the roving materials where the fibers were be more flexible in the horizontal directions specially when be without Nano because of vesical and mechanical properties for Nano carbon powder which prevent the elongation in the longitudinal direction , therefore it was clear that the increasing in the hoop strain (ε_H) for the woven roving Nano fiber glass composite pipe (G.M.N.4) more than all the other specimens with and without adding Nano at a rate of (51%) as shown in figure (9-b) .This result backing to adding Nano powder which strengthening the horizontal direction and prevent the elongation in longitudinal direction .

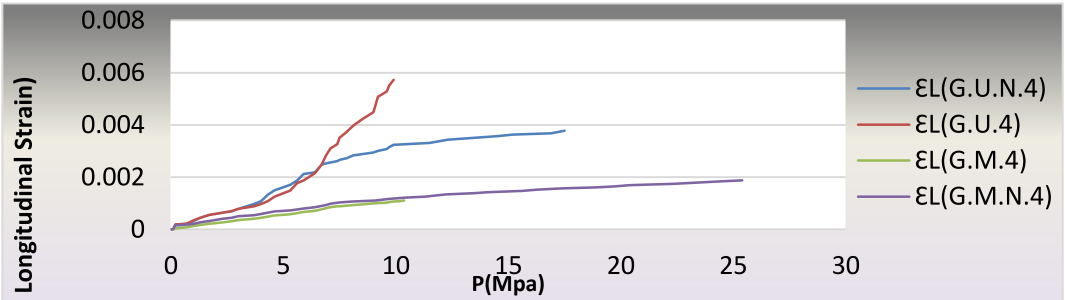
also it is clearing that the behavior of longitudinal stress for woven roving Nano fiber glass composite pipe (G.M.N.4) was more than other specimens with and without adding Nano by a rate of (31%) from the nearest point to it as shown in figure (9-c).This result back to the superlative mechanical and physical properties for Nano which it have shown a high potential improving properties of polymeric composite , in addition to the nature of the woven roving composite materials which have generate various deformation in the z-direction and appearing as a swelling in the middle of the specimen , also the hoop stress (σ_H) and Von Mises stress (σ_{von}) were noticeable increase in the stresses for woven roving fiber glass with Nano (G.M.N.4) than other materials by a rate of (31%) for each of them as shown in figure (9-d) and (9-e) and table (1) .

Table (1): Results for fiber glass with and without Nano

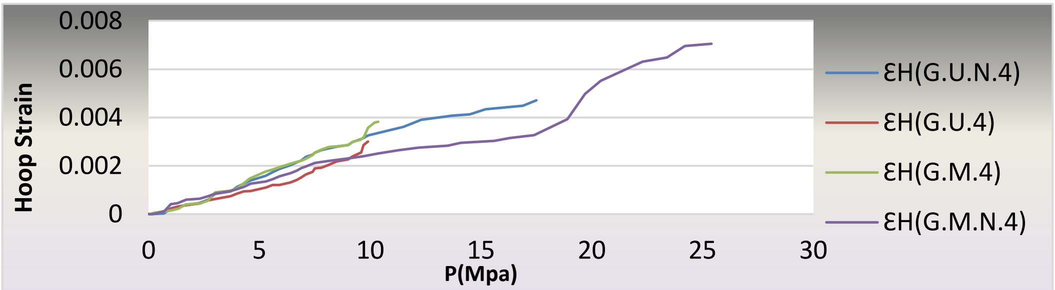
Mat.	P(Mpa)	ε_L	ε_H	$\sigma_{L\ (Mpa)}$	$\sigma_{H(Mpa)}$	$\sigma_{Von(Mpa)}$
G.M.4	10.4	.0011	.0038	61.7	130.4	112.9
G.M.N.4	25.4	.00187	.0071	159.1	319.1	276.3
G.U.4	9.9	.00573	.003	50.01	125.9	109.9
G.U.N.4	17.5	.0038	.0047	120.8	243.5	210.8

Where:

G.M.4 Fiber Glass Mat at 4mm thickness
G.M.N.4 Fiber Glass Mat Nano at 4mm thickness
G.U.4 Fiber Glass Union at 4mm thickness
G.U.N.4 Fiber Glass Union Nano at 4mm thickness



(a)



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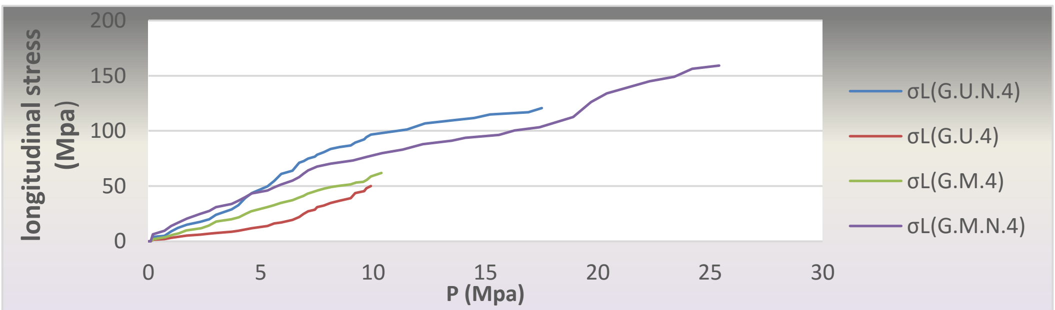
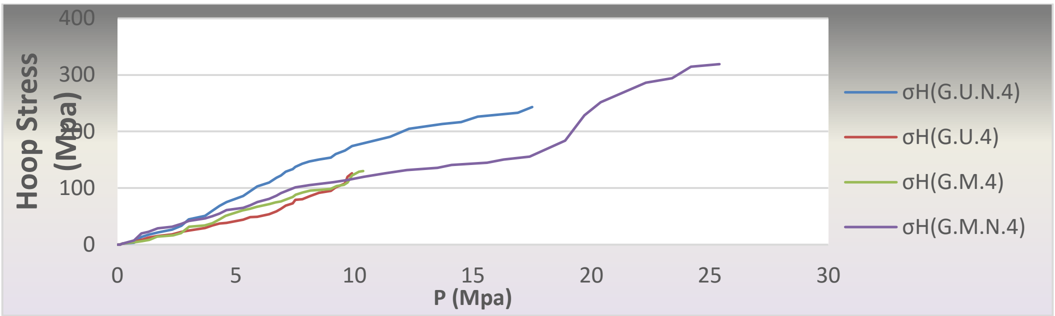


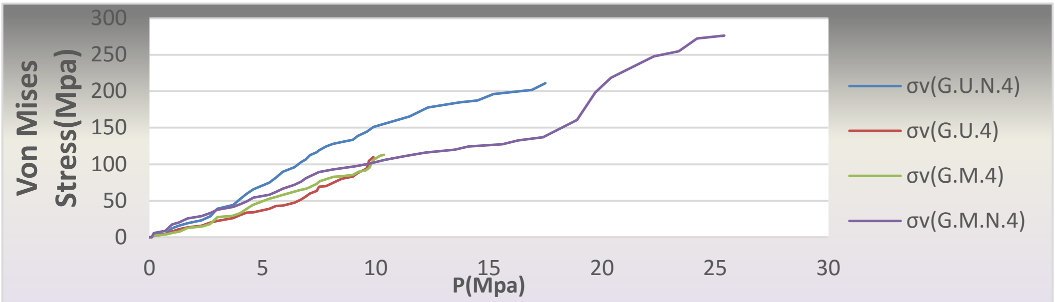
(c)

(a) Longitudinal strain (ε_L) (b) Hoop Strain (ε_H) (c) Longitudinal Stress (σ_L)
(d) Hoop Stress (σ_H) (e) Von Misses Stress (σ_{Von}).

Figure (9): The effects of pressure increment for fiber glass composite pipes on the longitudinal and hoop strain and stresses in:



(d)



(e)

Figure (9): continue

The same behavior for the same reasons which presented above for fiber glass founded for carbon. it was clear that the increasing in the hoop strain (ε_H) for the roving Nano carbon (C.U.N.4) in figure (10-a) was more than all the other materials with and without adding Nano by a rate of (17%).Figure (10-b) gives the effect of increasing pressure on the longitudinal strain (ε_L) for woven roving and roving with and without Nano carbon composite pipe [(C.M.4),(C.U.4),(C.M.N.4) and (C.U.N.4)]. It was noted that the longitudinal strain (ε_L) for the roving without Nano (C.U.4) was more than for the same specimens with adding Nano powder by (43%), also more than of woven roving with and without Nano, , as well as the hoop stress (σ_H) and Von Mises stress (σ_{von}) in figure (10-c)and figure (10-d) respectively show noticeable increase in the hoop and von misses stresses for woven roving carbon composite pipe with Nano more than other materials by(27%) for each of them. Figure (10-e) gives the relationship between the increase of pressure and the longitudinal stress (σ_L).It is clearing that longitudinal stress (σ_L) for woven roving Nano carbon composite pipe (C.M.N.4) was more than other materials with and without adding Nano by almost (40%) as it clearing in table (2).

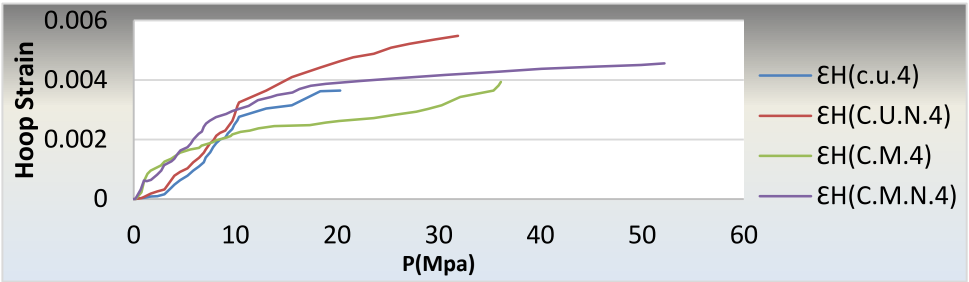
Table (2): Results for carbon with and without Nano

Mat.	P(Mpa)	ε_L	ε_H	$\sigma_{L\ (Mpa)}$	$\sigma_{H(Mpa)}$	$\sigma_{Von(Mpa)}$
C.M.4	36.1	.00089	.00393	269.3	507.9	440.2
C.M.N.4	52.2	.00149	.0046	377.3	646.6	562.6
C.U.4	21.6	.01221	.0039	90.1	258.5	227.2
C.U.N.4	31.9	.0085	.0054	217.8	425.7	368.7

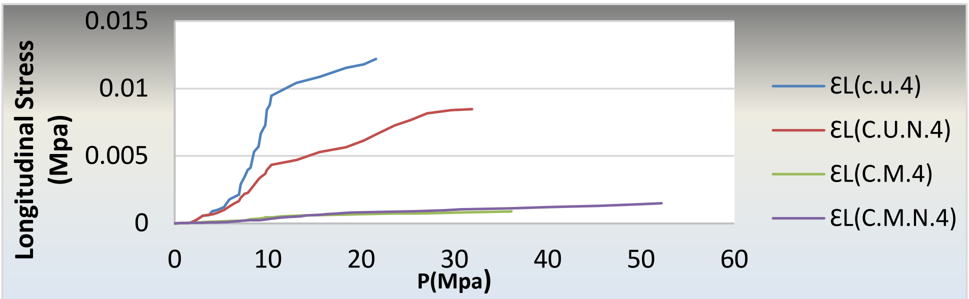
Where:

C.M.4 Carbon Mat at 4mm thickness

C.M.N.4 Carbon Mat Nano at 4mm thickness
C.U.4 Carbon Union at 4mm thickness
C.U.N.4 Carbon Union Nano at 4mm thickness



(a)



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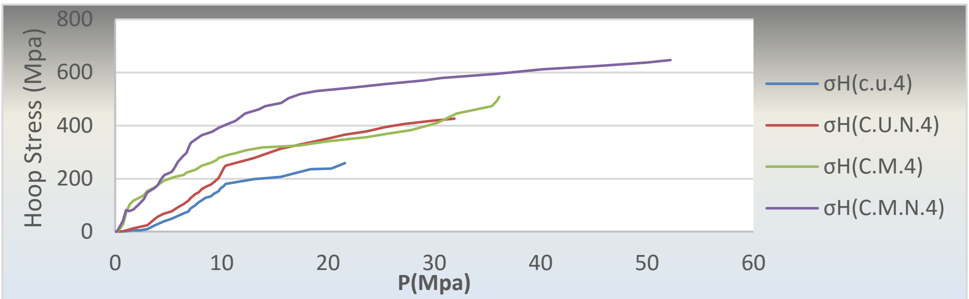
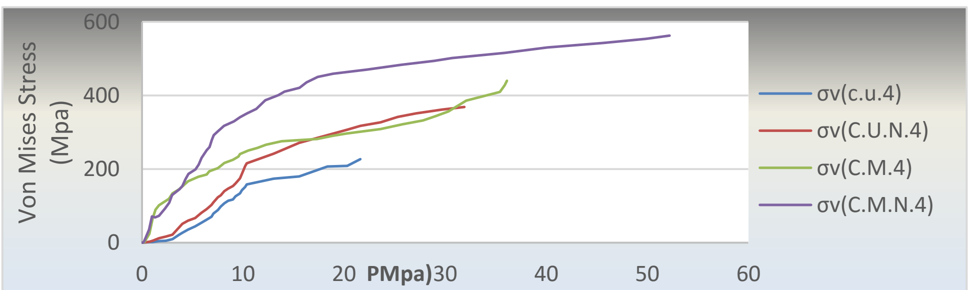


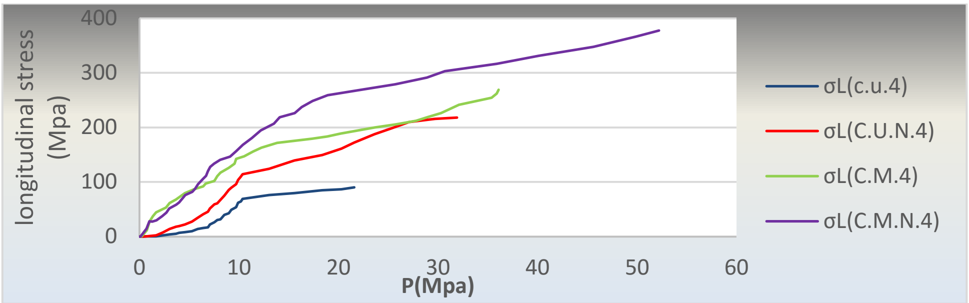
(c)



(d)

(a) Hoop strain (ε_H) (b) Longitudinal Strain (ε_L) (c) Longitudinal Stress (σ_L) ,
(d) Hoop Stress (σ_H) (e) Von Misses Stress (σ_{Von})

Figure (10): The effects of pressure increment for carbon composite pipes on the longitudinal and hoop strain and stresses in :



(e)

Figure (10): continue

In order to clarify the difference between the experimental, theoretical and numerical results of maximum (von Mises) stress for roving and woven roving Nano (fiberglass and carbon) respectively at (4mm)thickness(G.U.N.4),(C.U.N.4),(G.M.N.4) and (C.M.N.4), the results are listed in table (3).

It can be seen that reasonable difference between theoretical and experimental results ranging (0.4-11) % which is pointed by red color and small difference between numerical and theoretical results ranging (0.1-3) % which is pointed by yellow color.

Table (3): Theoretical, experimental and Numerical Results of Von Mises Stress (σ_{Von})

σ_{Von}(Mpa)	C.M.N.4	C.U.N.4	G.M.N.4	G.U.N.4
Theo.	565.08	345.32	274.9	189.8
Exp.	562.6	368.73	276.9	210.8
Error%	0.4	6	0.7	11
Num.	576	346	265	191
Error%	1	0.1	3	0.6

Where the theoretical specifications were been occurred from data sheet as shown in table (4):

Table (4): Modulus and Poisson Ratio for the Materials Used in This Study [Data sheet]

Material	Young's modulus(E) (Gpa)	Poisson Ratio (ν)
Fiber Glass (Mat)	72.4	.25
Fiber Glass (Union)	73.5	.59
Carbon (Mat)	230	.33
Carbon (Union)	130	.17
Epoxy	3.8	.33
Nano carbon powder	450	.19

7. Stresses Distribution of the Numerical Method

Figure (11) shows the stress distribution according to the numerical method for the pipe specimens. Stresses results showed that the value of stresses will be reduced or increased according to the type of stress.

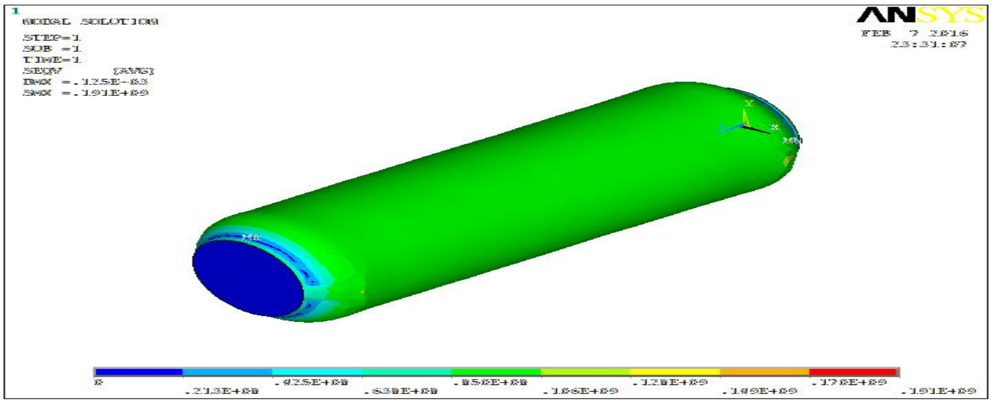
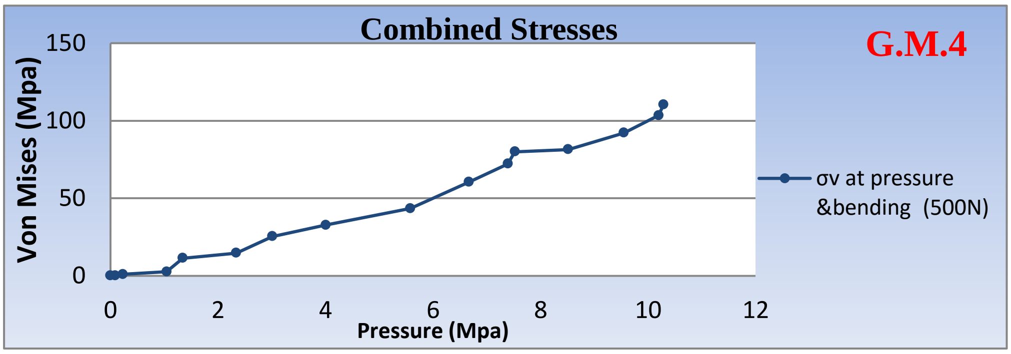


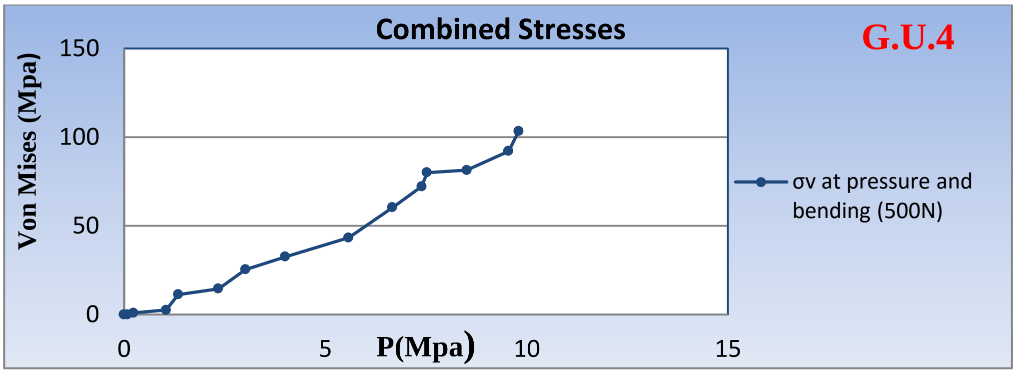
Figure (11): Stress distribution according to the numerical method

8. Applying Combined Internal Pressure and Bending Stresses

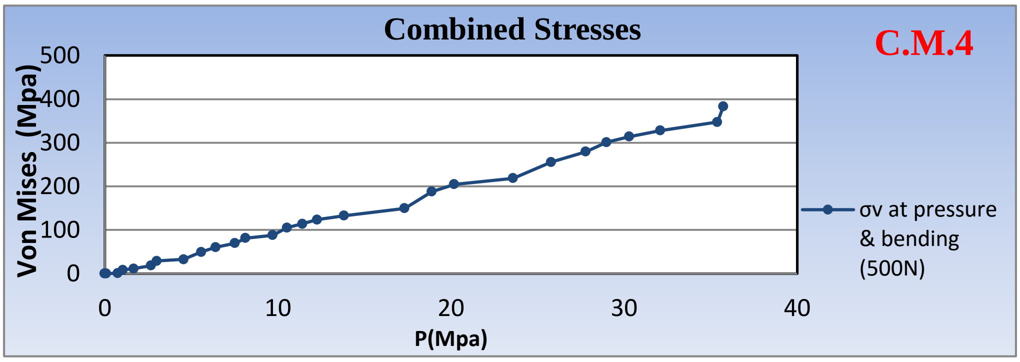
Figure (12-a) to figure (12-d) give the effects of increasing pressure and load up to (500N) on the von Mises stress (σ_{von}) for woven roving and roving fiber glass and carbon composite pipes at (4mm) thickness [G.M.4, G.U.4, C.M.4 and C.U.4] respectively .It can be observed that the pressure excess with increasing load up to (500N) causes enhancement in the von Mises stress (σ_{von}), As well as noted that the woven roving carbon (C.M.4)was greater than roving carbon (C.U.4) by a rate of (76%) and more than woven roving fiber glass (G.M.4) by (247%) and (264%) greater than roving fiber glass (G.U.4) .It was conclude that same sequence between the materials which it found when applying internal pressure between same materials , also noted that the percent of increasing von Mises stress (σ_{von}) between materials was less than when the specimens are subjected to effect of internal pressure only because of the effect of bending resulting from increasing load concurrently with increasing pressure.



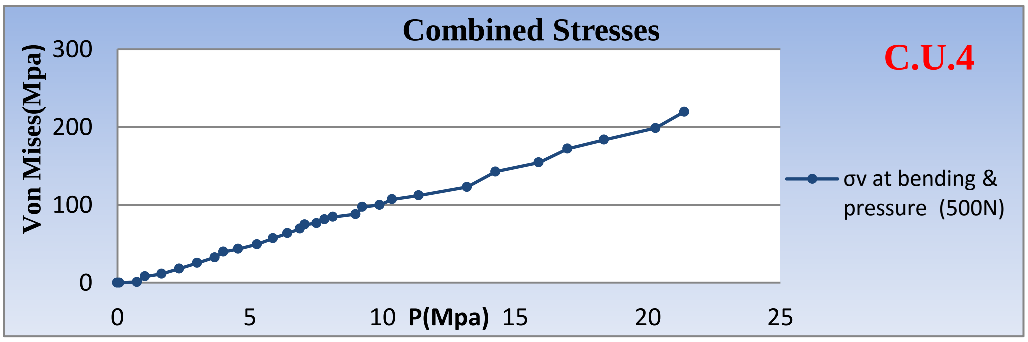
(a)



(b)



(c)



(d)

(a)for G.M.4 (b) for G.U.4 (c)for C.M.4 (d) for C.U.4 respectively.

Figure (12): Behavior of Von Mises stress (σ_{Von}) for woven roving and roving fiber glass also and carbon at (4mm) thickness versus variable pressure and load in:

9. Conclusions

1. all the materials used in this study with adding (2%) carbon Nano powder showed a significant improvement in the properties where adding carbon Nano powder makes carbon and fiber glass composite pipes sustains an increase in internal pressure and stresses were more than without adding Nano powder.
2. The maximum stresses for woven roving (fiber glass and carbon) composite pipes with Nano powder were more than without Nano by (144%) and (27%) respectively

While the maximum stresses for roving (fiber glass and carbon) composite pipes with Nano powder were more than without Nano by (91%) and (62%) respectively.

3.The increases of the maximum stresses for (woven roving fiber glass) composite pipes with Nano powder were more than of the increases for (woven roving carbon) composite pipes by (433%)while the increases of maximum stresses (Von Mises stresses) for (roving fiber glass) composite pipes were more than for (roving carbon) composite pipes by(46%) .

4. The increment of internal pressure was more affected than bending moment.

Abbreviations

A list of symbols should be inserted before the references if such a list is needed

$\sigma_{H,}\ \sigma_{L,}\ \sigma_r$	Hoop stress, Longitudinal stress, Radial
$\varepsilon_H,\varepsilon_L$	Hoop strain ,Longitudinal strain
E_H,E_1	Hoop modulus
E_l,E_2	Longitudinal modulus
ν_{LH},ν_{21}	Longitudinal to hoop Poisson ratio
ν_{HL},ν_{12}	Hoop to longitudinal Poisson ratio
$\sigma_{B,,}\sigma_{LB}$	Bending stress ,longitudinal –bending
σ_{von}	Von Misses stress

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