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A Study of some Mechanical Behavior on a Thermoplastic Material

Awham M. H. and Zaid Ghanem M. Salih
Department of Applied Science, University of Technology, Baghdad-Iraq.

Abstract

The aim of the current study is the investigation of mechanical behavior of thermoplastic material type (U-PVC) which may be subjected to effect of some mechanical stresses, because these materials are manufactured to use as drinking water, rainwater and heavy water pipelines.

Some tests were carried out on it, included: The (impact, modulus of elasticity (bending), flexural and compression) tests. These tests were performed to determine the ability of the material under study for these stresses.

The results which obtained from these tests at natural environments were analyzed and compared with other materials which were used in present studies.

These results showed that (Unplasticised PVC, (U-PVC)) material has high impact strength at these ambient, but obviously that there is great effect of notches on this property, as well as that the flexural strength and its ability for sustaining the compression failure is considered suitable if its compared with other materials.

Keywords: Thermplastic, Mechanical Properties, Impact, Compression, Bending, Flexural, Shear stress.

Introduction

Poly vinyl chloride (PVC) is one of the most important vinyl polymers that produced from petroleum (derivatives).

It's production coming as 2-nd class after polyethylene (PE) in the world.

There are two important kinds of PVC:

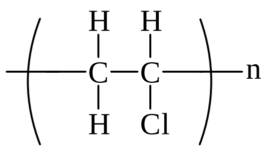
1. Rigid PVC which is used in fabrication of pipes and plastic plates (sheets).
2. Flexible PVC, which is composed from polymer with addition of plasticizers. This type of PVC used in fabrication of films, coating purposes and production of industrial leathers.[1]

So, PVC is one of the most important commercial plastics owing to its wide applications and low cost.

Despite its enormously technical and economic importance, PVC still possesses many problems such as low thermal stability and brittleness [2].

PVC without any additives, at room temperature, is a rather rigid material. It is often used instead of glass in many fields. But if it is heated to a temperature of about 87 °C, chemical change has been occur, PVC becomes flexible and rubbery [3].

The vinyl chloride monomer consists of a carbon-carbon double bond and a pendent chloride atom and three hydrogen atoms.



Where n is the degree of polymerization, i.e., the number of repeat units in the molecular chain. This monomer polymerizes by the addition (free radical) polymerization method [4].

When compared with PE and PP, unmodified PVC is more rigid, stronger, and more solvent sensitive.

PVC is largely amorphous and the size of chlorine atoms causes significant intermolecular interface and the polarity of Cl atom results in intermolecular attractions, thus increasing the tensile strength and modulus compared to PE and PP. The intermolecular attractions and general stiffness also increase the glass transition (Tg) and melting point (Tm) of PVC.

Tg of PVC is generally about (60-80) ºC. The sales of rigid PVC and vinyl are approximately equal [4].

PVC enters as an important material in construction industries, fabrication of rain coats, insulating material for an electrical wires, fabrication of furniture, and fabrication of cars [1].

It is largely used in fabrication of rigid pipes and frames of windows and doors. PVC competes rubber in many applications because of its excellent properties like [1]:

1. High electrical insulation.
2. High resistance for abrasion.
3. Low diffusion for humidity.
4. Good flexibility within range of temperatures.
5. Resistance to water, bases, acids, alcohols, oils, and aliphatic hydrocarbon components (compounds).

S. El-Raghi, R. R. Zahran, and B. E. Gebril [5] discussed the effect of weathering on mechanical and thermal properties of blends consisting of UPVC and Indulin Lignin (IL), that prepared by compression molding. Results showed that Lignin addition to PVC leads to an increase in tensile strength and a slight decrease in elongation at yield and at break for all specimens. Weathering did not affect the rate of change of the mechanical properties with Lignin addition.

Liling Zhou et al. [6] studied the influence of Chlorinated Polyethylene (CPE) and Acrylonitrile - Butadiene - Styrene Co-polymer (ABS) copolymer on the mechanical properties of PVC, i.e., PVC/CPE and PVC/ABS hybrids were examined. The experimental results showed that the toughness of the hybrids could be modified greatly by the introduction of the CPE or ABS. The Impact strength of PVC/CPE and PVC/ABS hybrids increased with the content of the 2^{nd} phase. CPE exhibited a better toughening effect than ABS.

Q. Yu and A. P. S. Selvaduri [7] studied the mechanical behavior of PVC subjected to ethanol exposure. Ethanol used in this work in different concentrations. The results showed that the exposure to pure ethanol resulted in a reduction in flexibility, or embrittlement, and the transformation of the PVC membrane from a flexible material capable of undergoing large strain hyperelastic behavior to a stiffer material with pronounced yield behavior.

Nesar Merah [8] studied the effect of weathering on some mechanical properties of CPVC (Chlorinated Polyvinyl Chloride). Tensile and single-edge-notch bending (SENB) specimens prepared from locally manufactured CPVC commercial pipes have been naturally weathered for different periods (1-9 months) in harsh Saudi weathering conditions. Standard tensile and SEN (single-edge-notch) fracture toughness tests were performed after natural exposure periods (1, 2, 3, … and 9 months). The tensile tests results showed that exposure of periods up to 9 months had limited effects on the tensile strength and modulus of elasticity of the material. While the value of fracture toughness showed a sudden drop in the 1^{st} month of exposure. Longer exposure periods resulted in a slow general decrease of material toughness.

In this work, several mechanical tests were carried out which are (Bending test, Flexural strength test, Impact strength test, and compressive strength test (the maximum stress that a material is capable of sustaining under compression)) for studying the behavior of U-PVC and recognize its properties when use in natural conditions.

Experimental Part

Samples were cut from a U-PVC pipe that made in K.S.A by (National factory for plastic industries-Jeddah city). Cutting of samples were done in agreement with global standards (ASTM, ISO, …) as shown in Table (1). Several mechanical tests were carried out in this work.

The instruments for measuring mechanical properties that used in this work can be clarified as follows: Impact test instrument, Bending test instrument, Flexural and compression test instrument.

- **Impact test**

Most (PVC) products as indeed other plastics are at risk of possible damage by impact at some points during their lifetime, either through accidental hits or drops. (e.g. PVC pipes during transport and installation; PVC containers in transport and storage). For these reasons the degree of resistance to breaking on impact, and its measurement, are of practical importance in the selection and comparison of plastics materials for particular applications, product design and quality assessments and control, [9].

The Charpy test was used. The type of scientific instrument which was used (TMI) which means (Testing Machine Incorporation). It was made in New York, U.S.A.

This test was carried out after cutting the samples with different depths of notches (0.25, 0.5, 0.75, 1, …, 2.5) mm.

The test piece is supported at both of its ends in a way that the hammer of instrument strikes it at the middle.

The Impact strength (I.S) is calculated by applying the following equation, [10]:

$I.S = Uc/A$ .... (1)

Where: Uc is the fracture energy (Joule) which is determined from Charpy impact test instrument.

(A) is the cross sectional area of the specimen$(mm)^2$.

Fig.(1) shows photographic image of some samples after the impact test.

- **Bending test**

This test is named as (3-points test) which was used to measure the Young's modulus of PVC samples. The instrument which was used in this work is made by Phywe company-Germany. The values of Young's modulus (E) are calculated from the equation, [11]:

$E = MgL^3/48IS$ .... (2)

Where: M/S is the slope of the curve that obtained from the relationship between the mass (M) and the deflection (S) of each sample, L is the distance between the two supports of the instrument (mm), g is const. (9.8 m/sec^2), I is the momentum of geometrical bending which can be calculated from the following equation, [11]:

$I = bt^3/12$.. (3)

Where: b, t are the width and thickness of the sample respectively. The result of (I) is measured by $(mm)^4$ while the units of (E) is MPa.

- **Flexural and compression test**

The term "flexural strength" or "modulus of rupture" is used for the surface stress in the beam when breaking occurs [12]. In other words, the flexural strength means the ability of the material to withstand bending forces applied perpendicular to its longitudinal axis, [12].

The strength of material depends on its ability to sustain a load without undue deformation or failure. This property is inherent in the material itself and must be determined by experiment. One of the most important tests to perform in this regard is the compression test, it is used primarily to determine the relationship between the average normal stress and average normal strain in many engineering materials [11, 12, 13]. This test was carried out to study the compression (stress-strain) behavior of PVC samples under investigation.

Both of these two tests are carried out with the same scientific instrument. It is the hydraulic piston, its type is Leybold Harris no.36110. For the first one (Flexural strength), 3-points test is performed. Flexural strength (F.S) and Shear stress (Ť) of the sample are determined from the following equations, [11]:

$F.S = 3ps/2bt^2$..(4)

$\check{T} = 3p/4bt$...(5)

Where: s is the span which means the distance between the two supported points of the sample (mm).

(b, t) are the width and thickness of specimen respectively(mm). P is the applied load (N).

The second test (compression), was carried out by using the digital micrometer which was used for (strain, ΔL) measurement where (L) is the length of sample (mm).

The value of the maximum load before the true fracture of the sample under test represents the ultimate compressive strength ($\sigma_{comp.}$) of this sample. The relationship of (F-Δℓ) can be modified for obtaining the relationship of stress (σ)-strain (ε) under the compression loading.

The numbers of standard specifications of the samples of all tests are listed in Table (1).

Fig.(2a) shows photographic image of the bending and flexural strength test samples.

Fig.(2b) shows photographic image of the compression test specimens.

Fig.(3) shows photographic image of the flexural test specimen after the testing.

Results and Discussion

- **Impact Strength test**

The impact test in general use to measure directly the total energy needed to break the test specimen by impact, [14]. Charpy impact test was used to evaluate the impact strength (I.S) of the PVC specimens that have (0, 0.25, 0.5, 0.75, 1, …, 2.5) mm notch depth. The results of this test are shown in Fig.(4), which illustrates the effect of notch depth on the impact strength values of UPVC under test. Fig.(4) demonstrates the impact strength of PVC type(U) is higher when the notch depth (a) equal zero, but when the notch depth increases gradually, the (I.S) will be decreased, this related to the decrease of the cross-sectional area of the sample that subjected to the impact, then the energy required to break the sample will decrease so the (I.S) will be decreased, [14].

From Fig.(4), it can be seen the difference between the (I.S) values of un-notched specimen and notched specimen. The reason behind this rapid drop in the impact strength value of notched specimen is related to role of notch which leads to concentrate stresses at the notch point (the material is sensitive to the presence of stress-concentrating features).

- **Bending test**

The modulus of elasticity indicates resistance to elastic deformation which is more commonly called stiffness [15]. In this test, the relation (mass-deflection) of (U-PVC) sample was obtained as shown in Fig.(5). It is recognized that the relation is linear, because the sample still within the elastic range of material, under the effect of the applied load. Table (2) illustrates the value of Young's modulus of PVC sample. This value indicates that (U-PVC) has a very high modulus of elasticity which is closed to that of metal [15].

- **Flexural strength test**

Three points bending test was used to evaluate the flexural strength (F.S) and shear stress (Ť) of standard PVC specimens. The results of this test are listed in Table (2).

According to the Bernoulli-Euler theory, the maximum flexural stress (σ_{max}) and the maximum interlaminar shear stress ($Ť_{max}$) exist at the surface of the specimen and at the neutral axis respectively. Therefore; the specimen can fail in a flexural mode at the surface or in a shear mode at the neutral axis, depending on which of (σ_{max}) and ($Ť_{max}$) becomes critical at the failure. In practice, however, a mixed failure mode can also occur when the flexural and shear failures take place simultaneously, [16, 17].

- **Compressive strength test**

Fig. (6) represents the relationship (Force-ΔL) of (U-PVC) specimen under compression test. Fig.(7) gives the (stress-strain) curve for (U-PVC) material. From this relation, The value of ultimate compressive strength ($\sigma_{comp.}$) was determined at the maximum stress that a material is capable of sustaining [11, 12, 13]. It is very important to remember that materials which do not fail by a shattering, this value is arbitrary depending on the distortion allowed, [13]. The value of ($\sigma_{comp.}$) is illustrated in Table (2).

From Fig.(7), it can be seen that U-PVC has two different behaviors, depending on the amount of strain induced in the material. The first is elastic (elastic region in the stress-strain curve) in which the stress is proportional to the strain, then, if the load is removed in this state, the specimen will return back to its original shape, but the other behavior is plastic and the deformation that occurs is called plastic deformation [11]. It is recognized that the fashion of failure of (U-PVC) material is buckling failure mode which always happen during compression test[13], but this material has considerable structural flexibility, which means that the material is able to withstand substantial axial deformation without permanent distortion, [9, 11].

The properties of materials are influenced in a complex way by many factors, which may be grouped under the following headings:

- Internal material factors: (composition, morphology, fine structure, presence of impurities).
- Effects of processing conditions.
- Design factors.
- External factors (temperature, nature of environment, …).

So that, the difference between the results values from each test and the limitation of standard specifications may be related to the defects and flaws which causes during the manufacture process of product or to the damage which is subjected to it through the carryings.

Conclusions

1- The presence of notches has largely effect on the impact strength (I.S) of (U-PVC) material previously. In general, it can be concluded that the (I.S) decreases with increasing the notch depth of the specimen.
2- It is found that the (U-PVC) has a large value of the modulus of elasticity, this reflect its high stiffness and rigidity.
3- According to the limitation of standard specifications (ASTM, ISO), the mechanical properties of (U-PVC) material under study is accepted.
4- The (stress-strain) curve which obtained from compression test indicates that the (U-PVC) has two behaviors, the first is elastic within the elasticity limit of the material and the second is plastic behavior which can be happened at the increasing of loading on the sample and at which, the material will not return to its original shape after removing the stress.
5- It can be noticed that the fracture nature of the impact test specimen is complete, this related to the effect of fast and sudden impact loading while under the effect of flexure and compression stresses, the material failed without obtaining the complete fracture, this indicates the ductility of U-PVC material and its sustaining of gradual stresses before the final failure.

Table (1)
Shows the standard specifications for the testing specimens.

Test	*Standard specifications*
Impact	ISO-179
Bending and Flexural strength	ASTM-D790
Compression	ASTM-D695

Table (2)
States the values of the mechanical properties under test.

Tests	*Impact strength I.S (KJ/m²)*	*Young's modulus E (GPa)*	*Flexural strength F.S (GPa)*	*Shear stressŤ MPa*	*Ultimate Compressive strength σ_{comp}. (MPa)*
Results	200.97 ± 5 at (a = 0)	224.5 ± 5	7.91 ± 5	42 ± 5	58 ± 5
ASTM Limitation	60, of notched specimen (ISO)	235	13.5	62	31-60

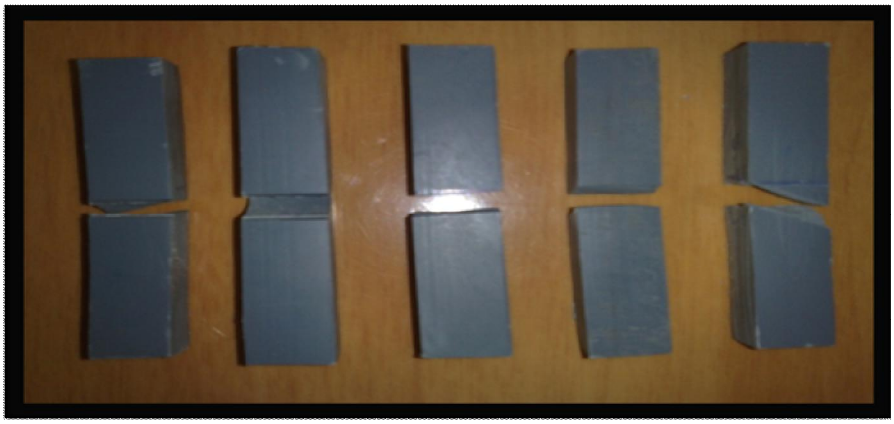


Fig. (1) The impact loading specimens after testing.

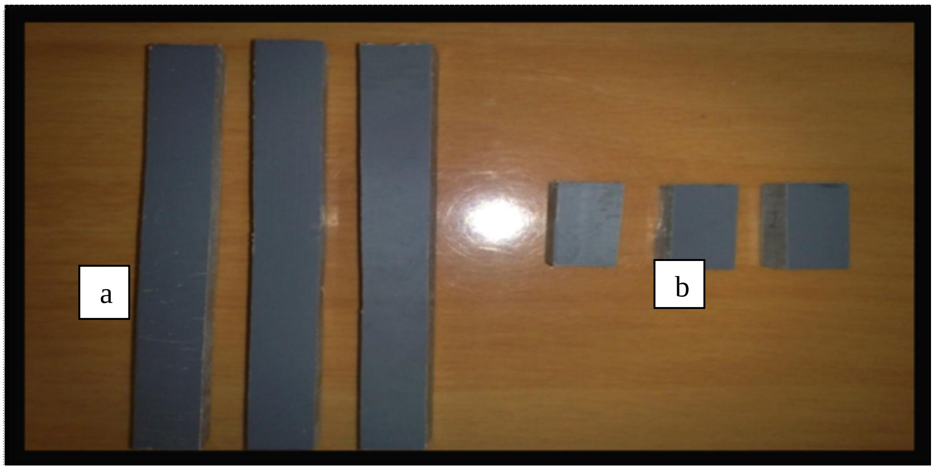


Fig.(2) (a) Bending test specimens, (b) Compression test specimens.

Fig.(3) Flexural test specimen after final failure.

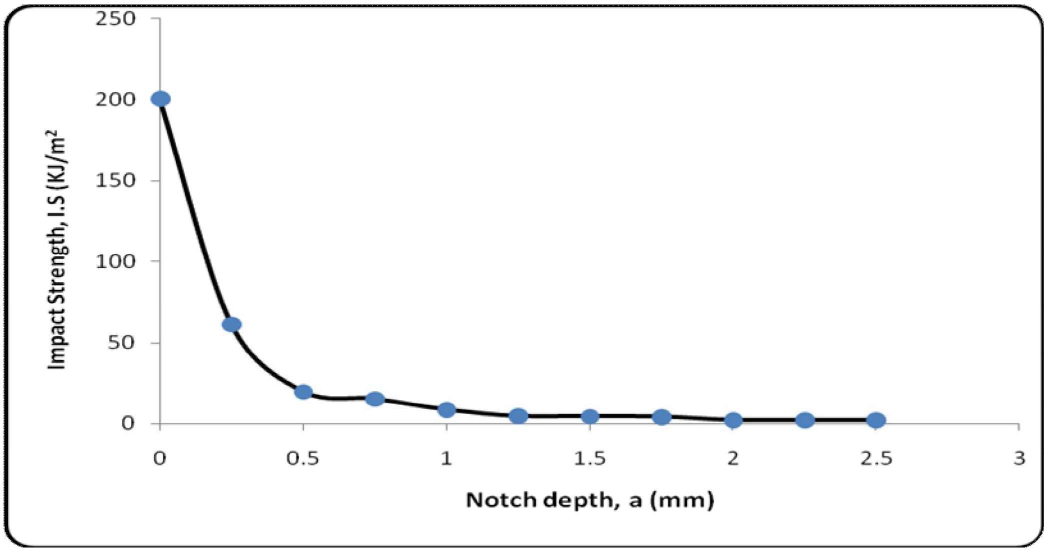


Fig. (4) Effect of notch depth on the impact strength of the (U-PVC).

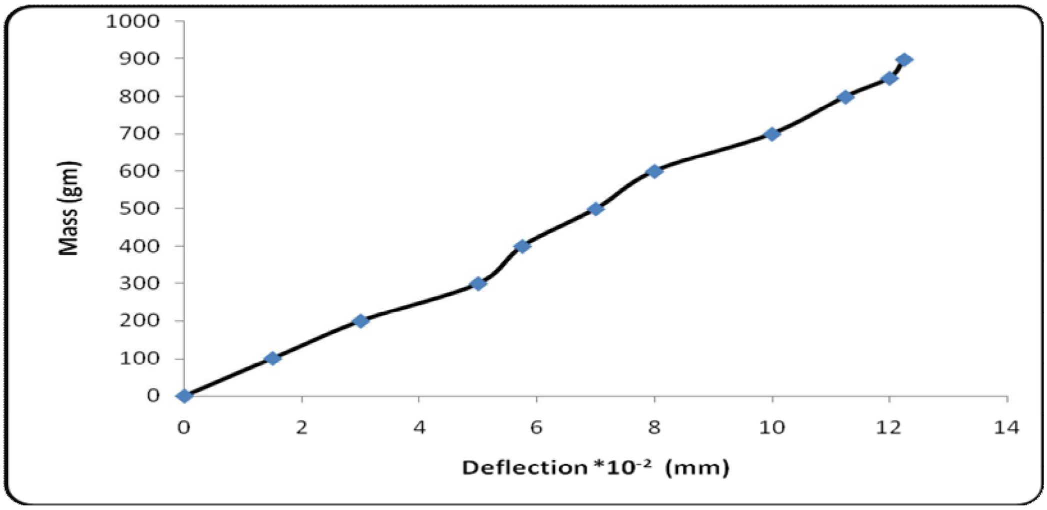


Fig. (5) The relationship between the mass and the deflection of (U-PVC) under the bending test.

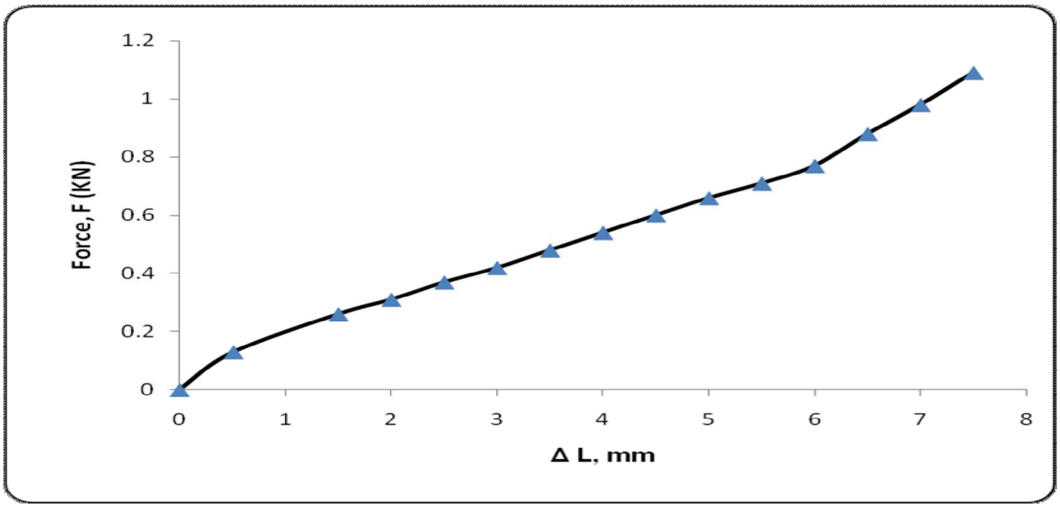


Fig. (6) The (Force-ΔL) curve of (U-PVC) under compression test.

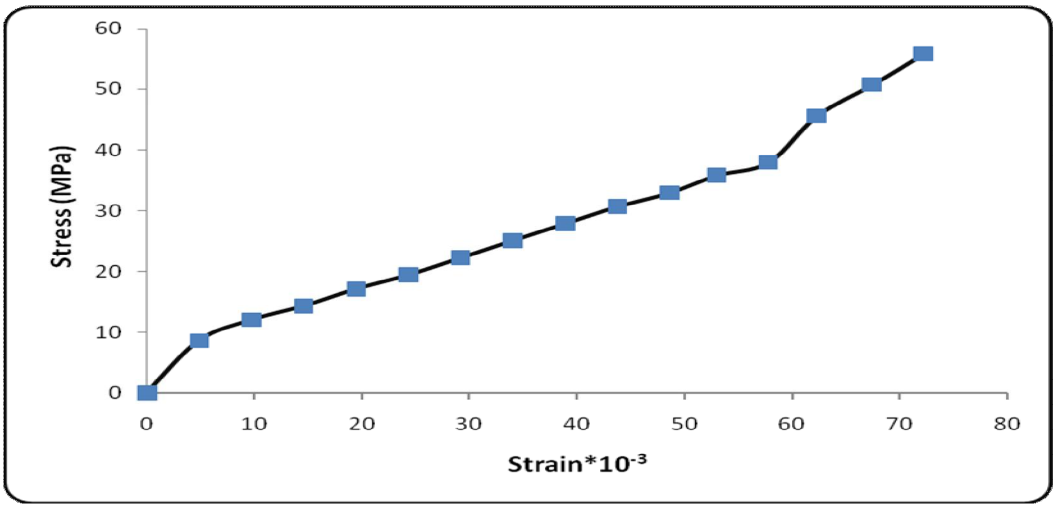


Fig. (7) The (Stress-Strain) curve of (U-PVC) under compression test.

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المقدمة

يهدف بحثنا الحالي الى دراسة السلوك الميكانيكي لمادة ثرموبلاستيكية نوع (U-PVC) اذا ما وقعت تحت تأثير بعض الاجهادات الميكانيكية لكونها تستعمل كأنابيب ماء الشرب ومياه الامطار والمياه الثقيلة. ولهذا الغرض أجريت لها مجموعة من الاختبارات شملت أختبار الصدمة ومعامل المرونة (الانحناء) ومقاومة الانحناء والانضغاط لاجل دراسة خصائص وسلوكية تلك المادة وتحديد مدى تحملها لمثل هذه الاجهادات والتي غالبا ما يتعرض لها هذا النوع من الانابيب اثناء الخدمة.

وبعد اجراء تلك الفحوصات العملية عند الظروف المختبرية تم تحديد النتائج لكل أختبارعلى حدة ، وبعد تفسيرها ومقارنتها بمواد اخرى أستخدمت في بحوث سابقة، وجد انها ذات مقاومة جيدة للصدمة ولكن في الوقت نفسه تبين بأن هنالك تأثير كبير لوجود الحزوز في المادة على تلك الخاصية كما ان مقاومتها للانحناء ومدى قابليتها على تحمل الفشل تحت تأثير الحمل الانضغاطي تعد مناسبة اذا ما قورنت بمواد اخرى.