MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

# EXPERIMENTAL DETERMINATION OF THE STRESSES AND STRAINS IN A THICK PVC CYLINDER REINFORCED BY A STEEL SHELL.

BY

Mohamed A. Gaballa*, Farouk M.F. Badran**

ABSTRACT

The proplem of theoritical determination of stresses and strains in a thick walled viscoelastic cylinder reinforced by steel shell and subjected to interinal pressure and external pressure (arising due to the elastic shell) had been treated by the authors |1,2|.To check the theoritically obtained solution of the discussed problem experimental investigations are carried out. In this experimental work the elastic shell is made of steel and the viscoelastic cylinder is made polyvinyle-chloride (PVC). The dimensions of the steel shell and PVC thick cylinder are estimated with reference to the actual rockets working with soild propellant fuel. The experimental tests are performed under constant pressure which corresponds to the steady conditions of the soild fuel rocket work. These tests are worked out on specimens of different diameters of steel shells and PVC cylinders with an apparatus designed specially for this purpose. The theoritical solution of the considered problem in case of PVC is obtained using the same analysis and computer program used before |2| . The only defference is that the mechanical constants $E_1$, $E_2$, $\eta_1$ and $\eta_2$ of the used before material is replaced by that of the PVC . To going through these theoritical investigations, the mechanical properties of the PVC must be measured this was carried out in another work |3|.

* Assistant Lecturer ** Professor Mechanical Engineering Department,Assiut University, Assiut, Egypt.

## EXPERIMENTAL ARRANGEMENT

The constructional drawing of the apparatus used for measuring strains in a thick walled viscoelastic cylinder reinforced by a steel shell and subjected to internal pressure is shown in Fig.(1), and the photograph in Fig.(2). The internal pressure is obtained from a container filled with liquid oxygen (of the type used in oxyacetyline welding) , which allows high pressure up to 150 kg/cm$^2$. The induced strains are measured by means of a strain gauge type PR 9833k/03 FE fixed on the tested cylinder in both circumferential and longitudinal directions. These strain gauges are connected to a multi-channel amplifier and ultravilot recorder (UVR). to amplify and record the strain signals. The high pressure for the test is obtained by connecting the liquid oxygen container though a regulating valve to the specimen. The internal pressure in the PVC cylinder is controlled by the mentioned above pressure regulating valve which is mounted in the outlet of the oxygen container.

For the solid propellant rocket fuel, burning takes place in a short time, then the internal pressure reaches the steady state high value in about one second. This high rate of pressure rise is obtained by sudden opening of the oxygen container vlave, and its time could be measured using the U.V.R.

The used test specimens are of different sizes (photograph 3). Each cylinder is fitted with almost zero clearance in a steel shell. The PVC cylinders are produced from PVC rods of 6.5, 6 and 4 cm. diameters. The steel shells are produced from weldless steel pipes with 6,5 and 3.5 cm. diameters , which are finely turned to the required dimensions. Low cutting speed , small depth of cut, small feed and sharp tools are used in turning and drilling of the PVC cylinders to decrease the generated heat which may change the properties of the surface layers of the PVC cylinders.The dimensions of the tested specimen are taken from a typical solid propellant rockets data. The dimensions of the used test specimens are given in the following table

Dimensions of the test specimens in mms.

| Dimensions \ Specimen No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Inner diameter of PVC cyl. | 24 | 24 | 24 | 12 | 16 | 18 | 28 |
| Outer diameter of PVC cyl. | 49 | 49 | 49 | 30 | 30 | 30 | 47 |
| Thickness of steel shell | 1 | 1.5 | 2 | 1 | 1 | 1 | 1 |

### Construction of the Pressurizing Apparatus

A solid propellant rocket fuel is subjected to internal pressure which induces radial and peripheral stresses. Therefore, the test specimen is loaded in a similar manner. For this purpose a PVC cylinder opened from both ends is mounted between two stands without considerable axial compression. The two stands are connected together with four tie rods to carry the axial load arising from the internal pressure.

Since the tested specimens are of different sizes,an adapter is constructed for each one to be used for fitting the specimen in the stands. Sealing rubber rings are squeezed between the test specimen and its adapter by the action of a sealing flange and four bolts to prevent oxygen leakage.

To avoid damage of the test specimen due to accedental pressure rise a safty valve is designed at the inlet side of the apparatus. The pressure is adjusted by the variation of the spring compression with the aid of a cover. Rubber sealing rings are used every where in the apparatus.

To measure the recovery in the viscoelastic cylinder, an unloading valve is constructed, Fig.1. The construction of the unloading valve is similar to the safty valve construction. The unloading valve stem 2 is threaded to the cross piece 3 which is hinged eccentrically to two discs 4. The two discs are welded to the handle 5. If the handle is rotated upward suddenly the valve will open suddenly to its maximum opening.

## Mounting of Strain Gauges

Three strain gauges are bonded on each specimen on the outer surface of the cylinder at the mid region.One of them takes the longitudinal direction and the others take the tangential direction. The strain gauges are bonded to the outer surface using adhesive material as "Alpha Cyanoacrylate". To avoid errors in measurements due to incorrect bonding and slipping, the surfaces to which the strain gauges are to be bonded are cleaned from greases and oils by liquid Acetone. And to compensate the effect of temperature, a dummy strain gauges are also used on a dummy test cylinders. Deep tool marks or deep scratches and scale rust are removed from the surface of the cylinders.

## Strain Measurement

Strain gauges are used to measure the strains in the outer surface of the cylinder. When the pressure is applied in the cylinder, the resistance of the strain gauge $R_1$ increases to $(R_1+\Delta R_1)$ due to the stretch on the outer surface of the cylinder, and the resistance $R_2$ of the dummy strain gauge remains constant. If the resistance $R_1$ equals to $R_2$ and both are connected with two equal resistances $R_a$ as shown in Fig.4, the bridge will be in balance and the voltage V will be equal to zero. After application of the pressure in the cylinder, the resistance $R_1$ of the active strain gauge will be changed and an unbalanced voltage will appear. The unbalance voltage is transmitted to a multichannel amplifier and the output signal is supplied to an ultraviolet recorder Fig.4.

## Pressure Measurment

A pressure gauge is used to indicate the pressure inside the test cylinder. To measure accurately and record the pressure, a pressure transducer is used. This pressure transducer changes the pressure into an electric signal (change of voltage due to change of capacitance) which is amplified and then recorded by the U.V.R. The electric connection of the pressure transducer, the six- channel amplifier and the U.V.R. recorder are shown in Fig.5.

## Calibration of Strain Gauge

The same test cylinder used in the pervious test with the same strain gauge bonded on it, is used in calibration to get the same conditions presented at the tests.The PVC cylinder is removed from the steel cylinder. Two plugs are inserted at the ends of the test cylinder with slight intereferance fit to prevent the damage of the shell by the clamping forces of the testing machine jaws. The AMSLER 10 tons tensile testing machine, in material testing laboratory of Assiut Faculty of Engineering, is used in the calibration test. The load is measured from the testing machine load indicator and the corresponding elongation is measured by Amsler extensometer reading with accuracy up to 0.005 mms . The obtained calibration curves of the UVR beam deflection are shown in Fig.6.

## COMPARISON BETWEEN THE THEORITICAL AND THE EXPERIMENTAL VALUES OF THE STRESSES AND THE STRAINS IN THE PVC CYLINDER AND IN THE STEEL SHELL

Figs.7 to 22 show a comparison between the experimental and the theoritical values of the stresses and strains in the PVC cylinder and elastic shell at different conditions. The effect of the PVC cylinder thickness and the steel shell thickness on the stresses and strains in the PVC cylinder and in the elastic shell is shown in Figs.11 to 22. As shown in these figures there is a good agreement between the experimental and the theoritical results. The percentage error in each case is given in the corresponding figure. It will be noticed that the deviation between the experimental and the theoritical results are one directional. The reason for this deviation is mentioned below in reference to each figure.

Fig.7 shows a comparison between the theoritical and the experimental values of the circumferential strain at the outer surface of the PVC cylinder as function of time. It is noticed that the experimental results are always lower than the theoritical ones, this is due to the tensile longitudinal strain induced during the experiment. As indicated by the gauges this tensile strain in the longitudinal direction is smaller than the strain in the circumferential direction. It is also clear from Fig.7 that the agreement between the theoritical and the experimental results is better in the short time periods, which is of more interest because the working time of any solid propellant rocket is small ranging from some seconds to a few minutes.

Fig.8 shows a comparison between the theoritical and semiexperimental values of the circumferential strain at the inner surface of the PVC cylinder as function of time. It is also noticed that the experimental results are always lower than the theoritical ones due to the same reason mentioned above. Also there is better agreement in the short time periods.

Fig.9 shows a comparison between the theoritical and the experimental values of the radial stress at the steel shell as function of time. The theoritical results are higher than the semiexperimental ones due to the same reason mentioned above, and the agreement between the theoritical and the semiexperimental values are good in the short time periods.

Fig.10 shows a comparison between the theoritical and the experimental values of the circumferential stresses in the steel shell as function of time. It is noticed from this figure that, the experimental values are always smaller than the theoritical ones due to the tensile longitudinal strain induced during the experiments. Fig.10 shows also a comparison between the theoritical and the semiexperimental values of the circumferential stress at the inner and outer boundaries of the PVC cylinder. The small experimental values of the circumferential stresses in the steel shell, means that the steel shell is more rigid and the relaxation of the PVC cylinder is decreased, for this reason the semexperimental values of the circumferential stresses at the inner boundaries of the PVC cylinder is higher than that of the theoritical ones as it is clear from Fig.10. In the short time periods there is better agreement between the theoritical and the semiexperimental values.

Fig.11 shows the effect of the steel shell thickness on the circumferential strain at the outer surface of the PVC cylinder and the experimental points. It is clear from Fig.11 that the circumferential strain at the outer boundary of the PVC cylinder decreases with the increase of the steel shell thickness. Good agreement between the theoritical and the experimental results is noticed for all times.

Fig.12 shows the effect of the steel shell thickness on the circumferential strain at the inner boundary of the PVC cylinder and the semiexperimental points. It is clear from this figure that as the steel shell thickness increases the circumferential strain at the inner boundary of the PVC cylinder decreases. The agreement between the experimental and the theoritical results is good.

Fig.13 shows the effect of the steel shell thickness on radial stresses at the steel shell. It is clear from this figure that as the steel shell thickness increases the radial stress increases. It is also clear from this figure that, the experimental values of the radial stress is lower than the theoritical ones in the specimen with h=1 mm. This is due to the tensile longitudinal stress. But for the specimen with h=2 mm, the experimental values of the radial stress are higher than the theoritical ones due to the compressive longitudinal stress induced during this experiment. Percentage error between theoritical and semiexperimental points ranges from 0 to 4.5.

Fig.14 shows the effect of the steel shell thickness on the circumferential stress at the inner boundary of the PVC cylinder and the semiexperimental points. It is clear from this figure that, as the steel shell thickness increases, the circumferential stress decreases. It is noticed also from the same figure that, the experimental values are higher than the theoritical ones in the case h=1 mm, because the tensile longitudinal stress in the elastic shell which induced during the experiments, decreases the values of the circumferential stresses in the steel sheel, which lower the relaxation of the PVC cylinder and this makes the theoritical values of the circumferential stress in the inner and outer boundary of the PVC cylinder higher than the experimental ones. But the inverse of this case is noticed for the specimen with h=2 mm, where the experimental values of the circumferential stresses in the PVC cylinder are lower than the theoritical ones due to the compressive longitudinal stress in the steel shell which increase the circumferential stress in the steel shell and permit the PVC cylinder to relaxe and the theoritical values of the circumferential stress in the PVC cylinder becomes higher than the experimental values. The agreement between the theoritical and experimental results is noticed in the short times except at t=0 to 2.5 sec., where the error is relatively higher. This is may be due to the error in measuring the mechanical properties of the PVC material in the very short times.

Fig.15 shows the effect of the steel shell thickness on the circumferential stress at the outer boundary of the PVC cylinder and the semiexperimental points. It is clear from this figure that as the steel shell thickness increases the circumferential stress at the outer boundary of the PVC cylinder decreases. The same remarks and reasons mentioned for Fig.14 are valid with respect to Fig.15.

Fig.16 shows the effect of the steel shell thickness on the circumferential stress in the steel shell. It is clear from this figure that, as the steel shell thickness increases, the circumferential stress in the steel shell decreases.

Fig.17 shows the effect of the PVC cylinder thickness on the circumferential strain at the outer boundary of the PVC cylinder and the experimental points. It is clear from figure 17 that as the PVC cylinder thickness decreases, the circumferential strain at the outer boundary increases. And it is noticed from this figure that,the deviation between the experimental values of the circumferential strain at the outer boundary are lower than the theoritical ones. This is due to the tensile longitudinal strain induced during the experiments. The agreement between the theoritical and experimental results are very good in the short times.

Fig.18 shows the effect of the PVC cylinder thickness on the circumferential strain at the inner boundary of the PVC cylinder and the semiexperimental points. It is clear from this figure that, as the PVC cylinder thickness decreases the circumferential strain at the inner boundary decreases. And also, the experimental values are lower than the theoritical ones, due to the tensile longitudinal strain induced during the experiments.

Fig.19 shows the effect of the PVC cylinder thickness on radial stress at the steel shell and the semiexperimental points. It is clear from this figure that, as the PVC cylinder thickness decreases the radial stress at the steel shell increases.

Fig.20 shows the effect of the PVC cylinder thickness on the circumferential stress at the inner boundary of the PVC cylinder and the semiexperimental points. It is clear from this figure that, as the PVC cylinder thickness decreases, the circumferential stress at the inner boundary decreases. The deviation between the theoritical and the experimental values is larger in short time from t=0 up to 2.5 sec.

Fig.21 shows the effect of the PVC cylinder thickness on circumferential stress at the outer boundary of the PVC cylinder and semiexperimental points. It is clear from this figure that, as the PVC cylinder thickness decreases the circumferential stress at the outer boundary increases. Good agreement between the theoritical and the experimental values is noticed except at times from t=0 up to 2.5 sec.

Fig.22 shows the effect of the PVC cylinder thickness on the circumferential stress in the steel shell and experimental points. It is noticed that the circumferential stress in the steel shell increases as the PVC cylinder thickness decreases. Good agreement between experimental and theoritical points is noticed except for the period from t=0 to t=10 sec.

Generally, some deviations between the theoritical and the experimental results may be due to the error in measuring the mechanical properties (the relaxation function) of the PVC material. The specimens used in this work are machined from the PVC rods produced by THE PLASTIC NATIONAL COMPANY. Some small blow holes are noticed in some rods near their axes. Such defects affect the experimental results and increase the error between experimental and theoritical results. The relations shown by figures from 10 to 22 for periods equal 60 seconds are obtained for periods equal 120 minute but are not shown here.

## CONCLUSION

From the theoritical and experimental investigation carried out in this work on the thick walled viscoelastic cylinder reinforced by elastic shell, we can make the following conclusions

1- The good agreement between the experimential and the theoritical results

6

obtained for the stresses and strains in the viscoelastic cylinder and in the elastic shell demonstrates that, the used theoritical bases are accurate and the made assumptions are valid to enough degree. This means, also that the choosed in this work model for the viscoelastic material is justified.

2- Using the obtained here curves as a guide, we can, for solid propellant rocket fuel determine the optimum value of the fuel thickness and the elastic shell thickness, which are the most important parts of the solid propellant rocket. Since, as mentioned in the discussion, the circumferential and radial stresses in the elastic shell are relatively small in periods shorter than the relaxation time, then it is recommonded to select such fuel with large relaxation time and the total working time of the solid propellant rocket must be made considerably smaller than the relaxation time. The relaxation time of the fuel can be determined using the measured experimentally relaxation function.

3- The effect of the viscoelastic cylinder thickness on the radial and circumferential stresses, has a larger effect in the earlier period of loading, and near to the relaxation period the difference becomes not unconsiderable.

4- The effect of the elastic shell thickness and the effect of the elastic shell strength on the radial and circumferential stresses, has a large effect in the early time of loading.

REFERENCES

1- Farouk M.F.Badran. "Viscoelastic stresses due to large strains caused by internal burning and pressurization of solid propellent grains" First. Cairo Univ. Conf. on M.D.P. Vol.2, 1979.

2- Mohamed A. Gab-Allah, Farouk M.F. Badran. "Thermal stress and strain analysis in a linear viscoelastic cylinder with temperature dependent properties reinforced by elastic shell using actual relaxation function. Proc. First Conf. on Th. and Ap. Mech. Cairo 16-18/13/1980 Acad. Sc. R. and Tech.

3- Farouk M.F.Badran and Mohamed A. Gab-Allah. "Analysis of elastic and viscous properties of linear viscoelastic bodies" Delivered for publication in this present conference.

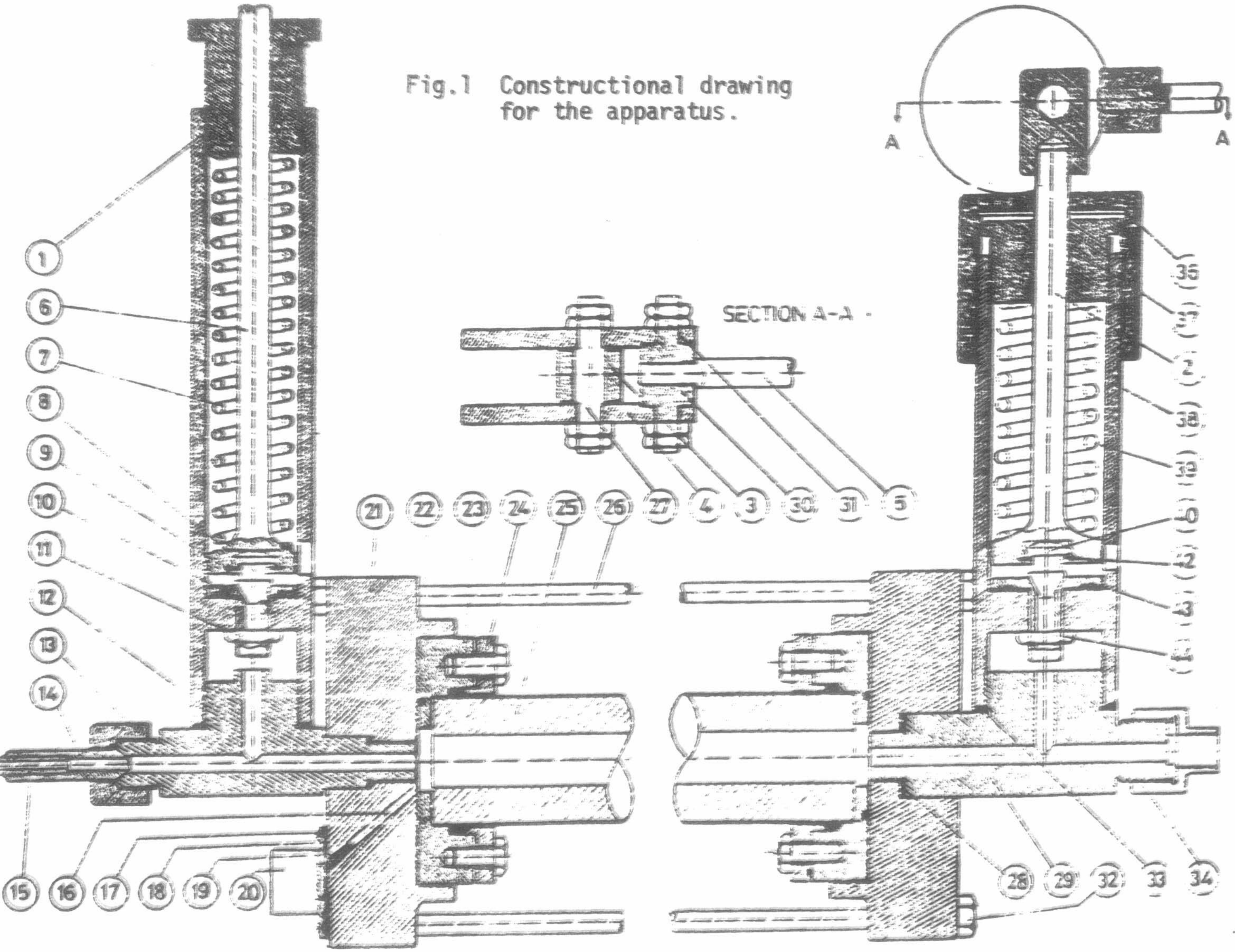


Fig.1 Constructional drawing for the apparatus.

1-Regulating Cover, 2-Unloading valve stem, 3-Cross Piece, 4-Eccentric disc, 5-Handle, 6-Safty valve stem, 7-Safty valve spring, 8-Taper valve, 9-Circlips, 10-Safty valve seat, 11-Nut, 12-Safty valve base, 13-Nut, 14-Nipple, 15-Pipe, 16-Slot, 17-Set screw, 18-Gasket, 19-Short pipe, 20-Pressure trans. 21-Stand, 22-Adapting disc, 23-Bolts, 24-Sealing flange, 25-PVC cylinder, 26-Tie rod, 27-Pivot, 28-Gasket, 29-Unloading valve base, 30-Cross piece 31-Nut, 32-Nut, 33-Rubber sealing ring, 34-Joining double nut, 35-Nut, 37-Regulating Cover 38-Unloading valve body, 39-Unloading valve spring, 40-Taper valve, 42-Circlips, 43-Seat, 44-Nut.

6

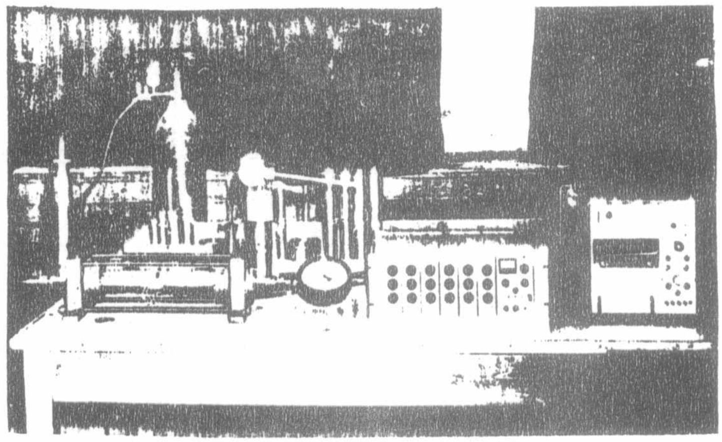

Fig.2: Photograph for the apparatus.

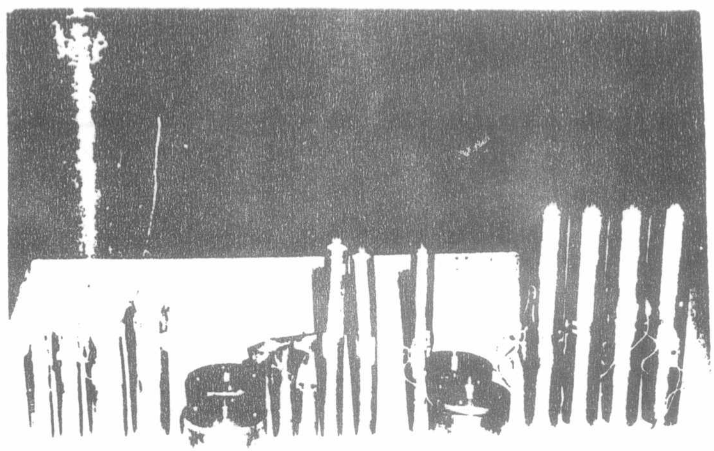

Fig.3: Photograph for specimens.

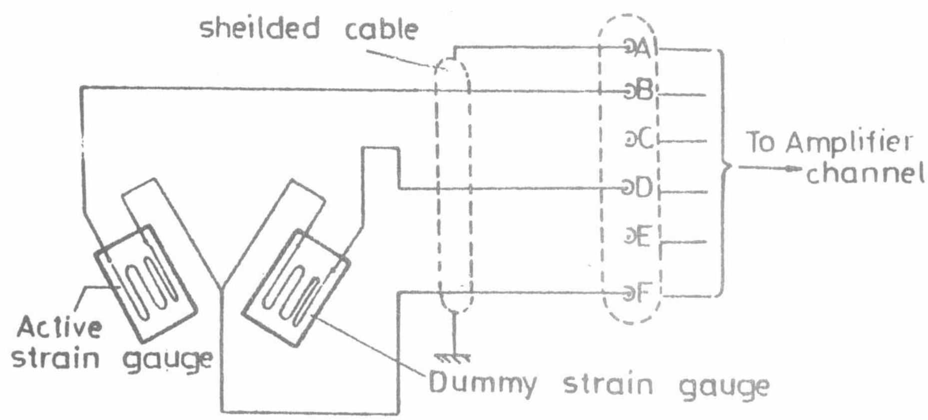


Fig.4: Circuit diagram for the strain gauge.

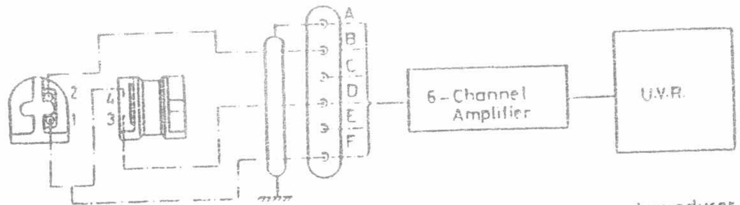


Fig. 5 Installation and circuit diagram for the pressure transducer.

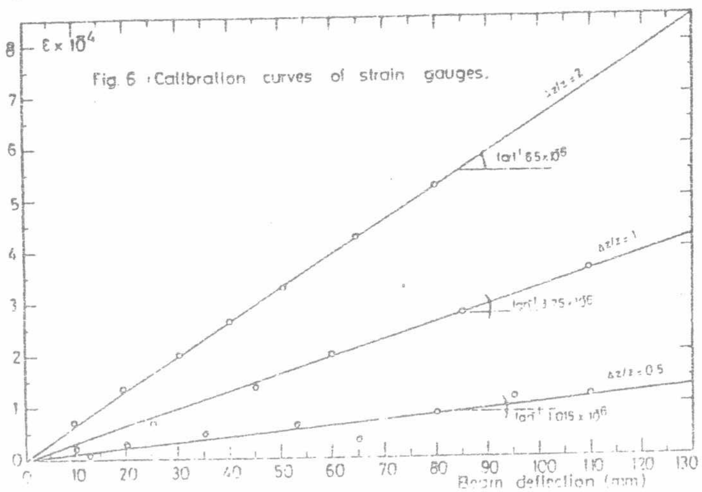


Fig. 6 : Calibration curves of strain gauges.

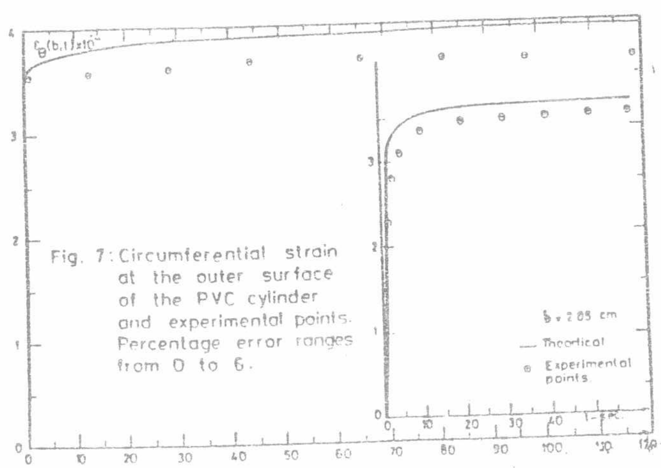


Fig. 7 : Circumferential strain at the outer surface of the PVC cylinder and experimental points. Percentage error ranges from 0 to 6.

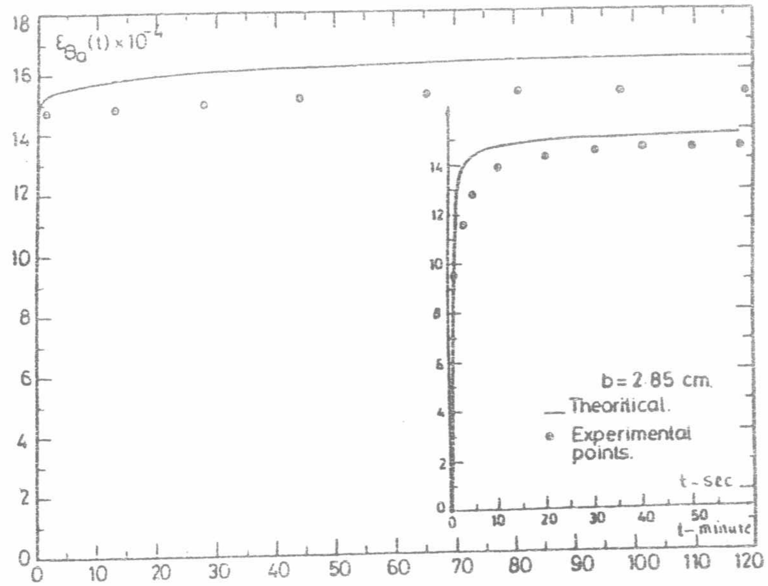


Fig. 8 Circumferential strain at the inner surface of the PVC cylinder and semiexperimental points. Percentage error ranges from 0 to 6.

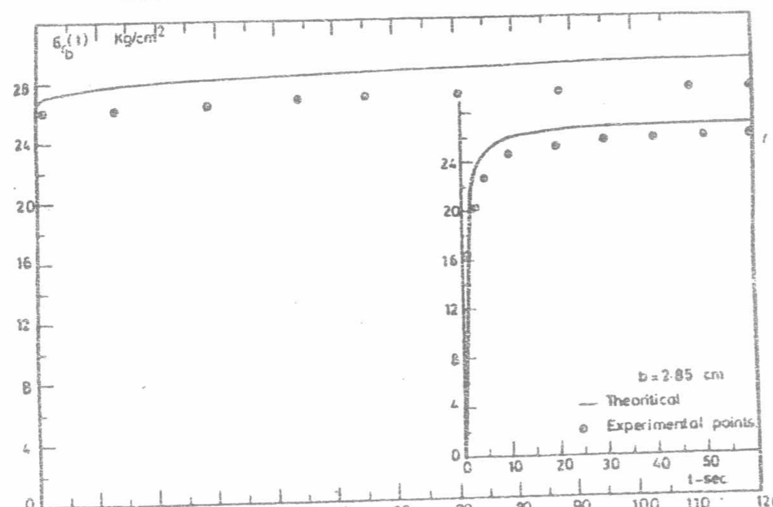


Fig. 9 Radial stress at the steel shell and semiexperimental point. Percentage error ranges from 0 to 2.

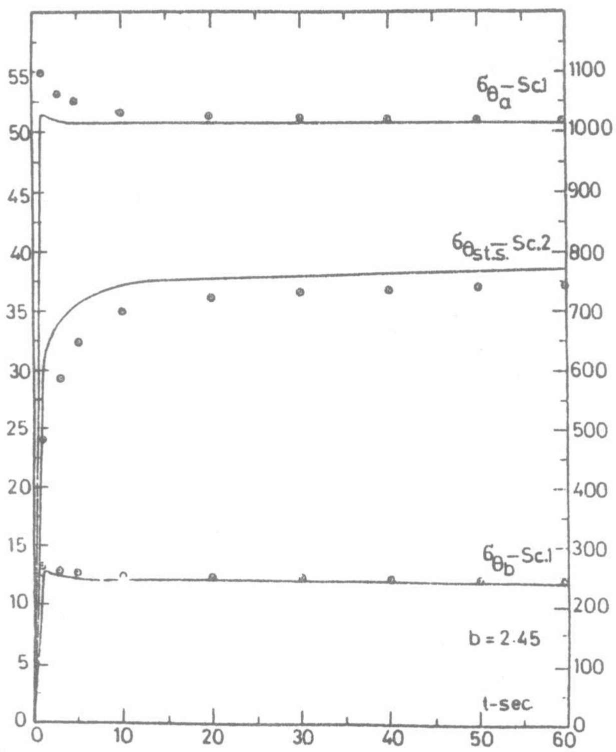


Fig.10 Circumferential stresses in the PVC cylinder and in the steel shell and semiexperimental points. Percentage error ranges from 0 to 4.

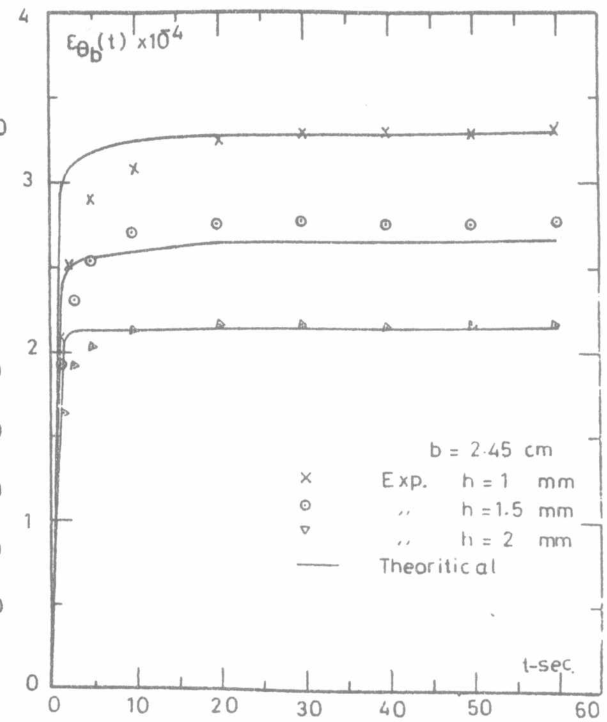


Fig.11 Effect of the steel shell thickness on the circumferential strain at the outer boundary of the PVC cylinder and experimental points. Percentage error ranges from 0 to 3.

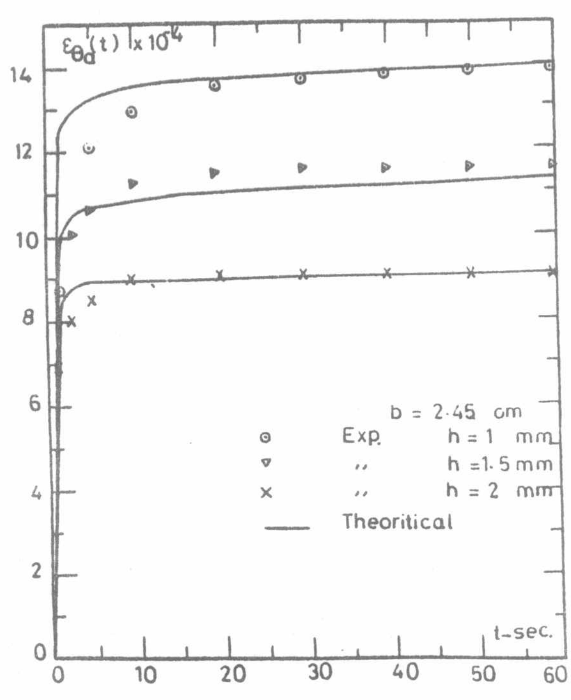


Fig.12 Effect of the steel shell thickness on circumferential strain at the inner boundary of the PVC cylinder and semiexperimental points. Percentage error ranges from 0 to 7

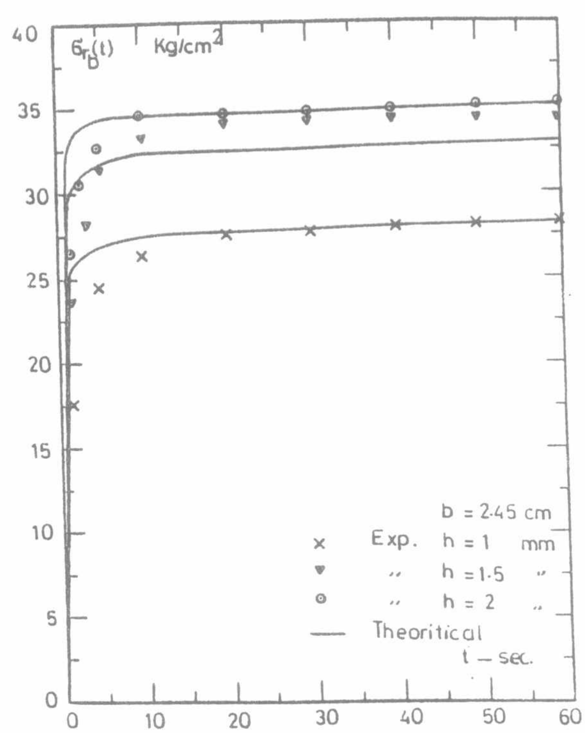


Fig. 13 Effect of the steel shell thickness on radial stress at the outer boundary of the PVC cylinder and semiexperimental points. Percentage error ranges from 0 to 4.5.

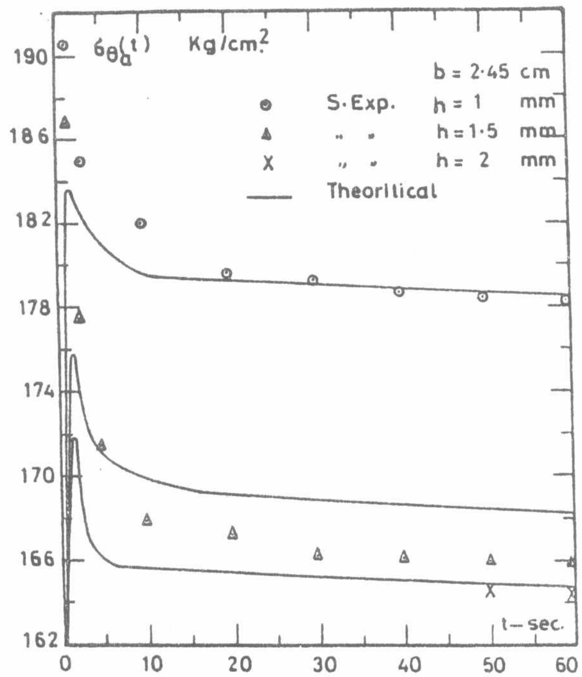


Fig.14 Effect of the steel shell thickness on circumferential stress at the inner boundary of the PVC cylinder and semiexperimental points. Percentage error ranges from 0 to 3.

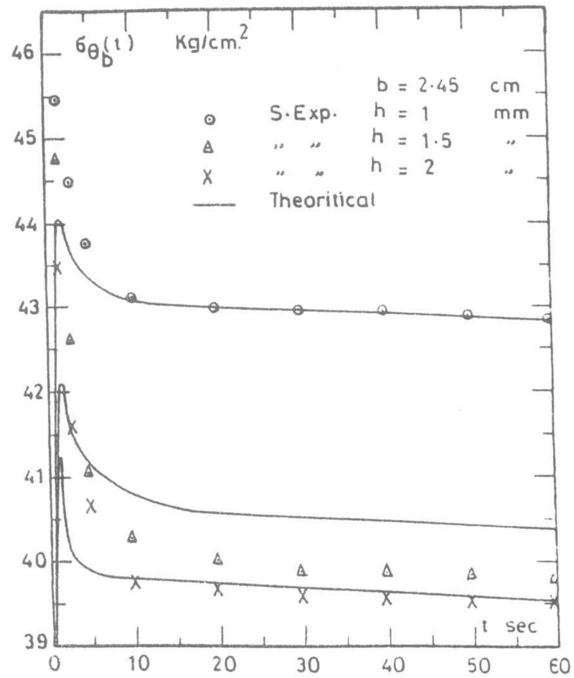


Fig.15 Effect of the steel shell thickness on circumferential stress at the outer boundary of the PVC cylinder and semiexperimental points. Percentage error ranges from 0 to 3 .

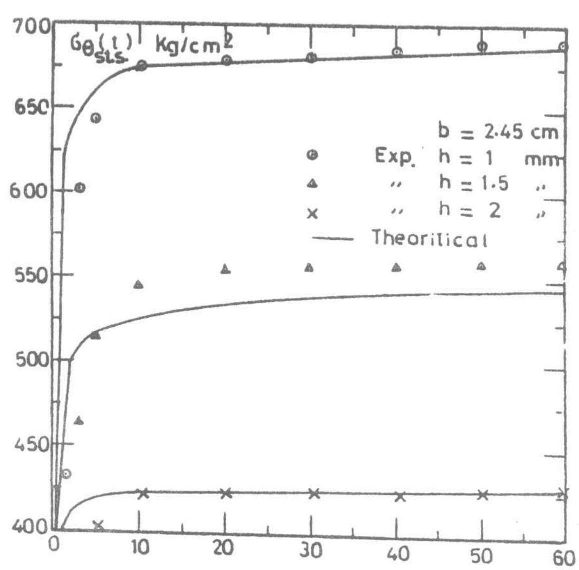


Fig.16 Effect of the steel shell thickness on circumferential stres stress in the steel shell and experimental points. Percentage error ranges from 0 to 3

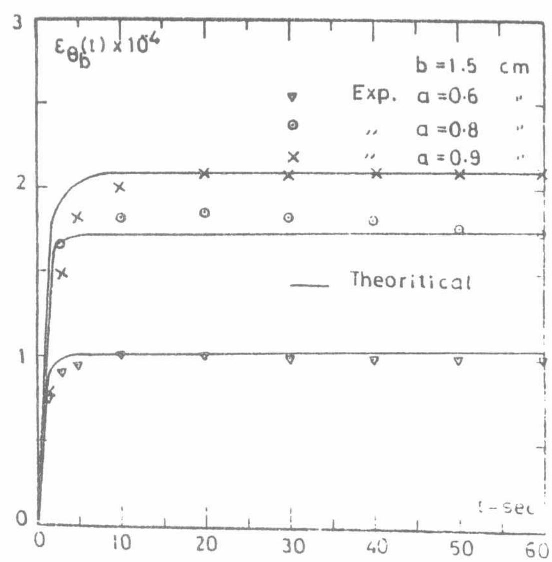


Fig.17 Effect of the PVC cylinder thickness on circumferential strain at the outer boundary and experimental points. Percentage error ranges from 0 to 6.

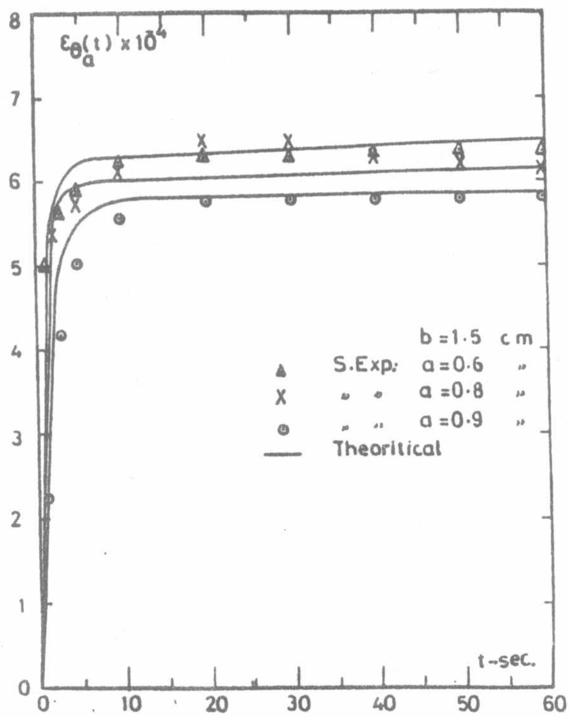


Fig.18 Effect of the PVC cylinder thickness on circumferential strain at the inner boundary of the PVC and semiexperimental points. Percentage error ranges from 0 to 5 .

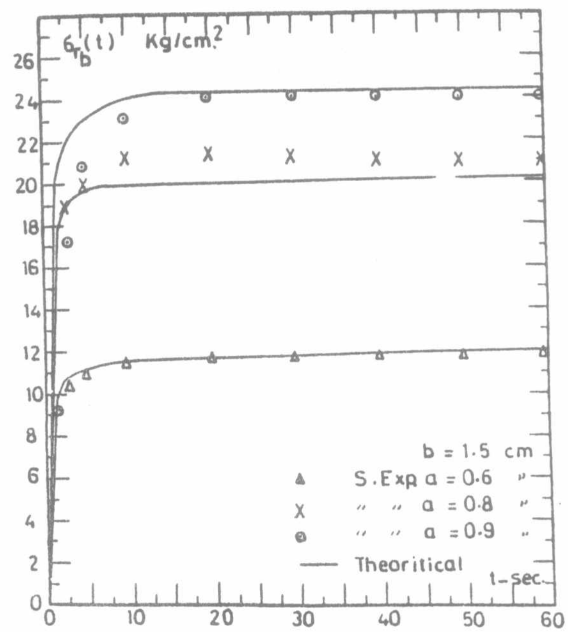


Fig.19 Effect of the PVC cylinder thickness on the radial stress at the steel shell and semiexperimental points. Percentage error ranges from 0 to 5 .

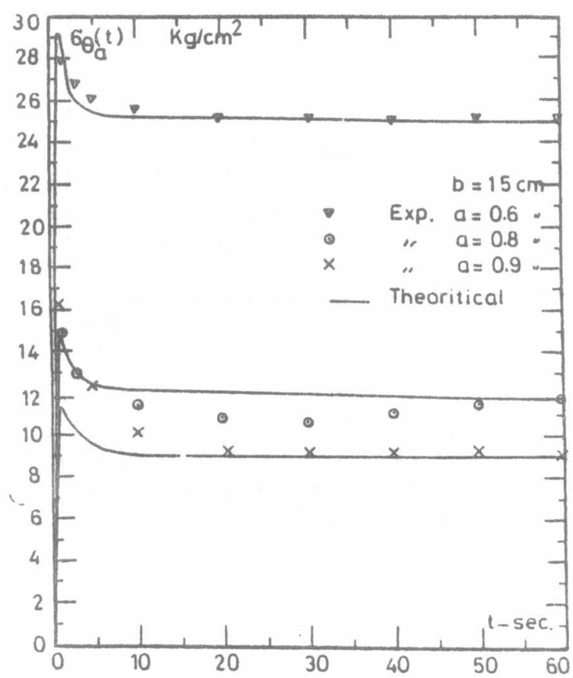


Fig.20 Effect of the PVC cylinder thickness on circumferential stress at the inner boundary of the PVC cylinder and semiexperimental points. Percentage error ranges from 0 to 4 .

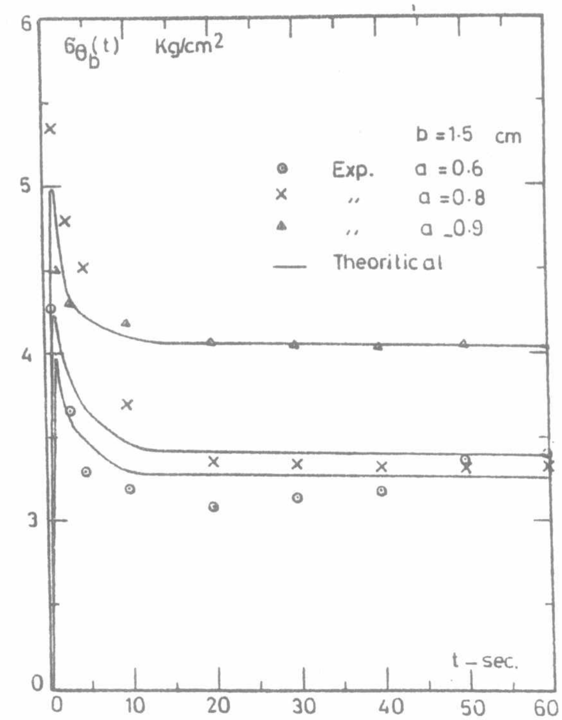


Fig.21 Effect of the PVC cylinder thickness on circumferential stress at the outer boundary of the PVC cylinder and semiexperimental points. Percentage error ranges from 0 to 6 .

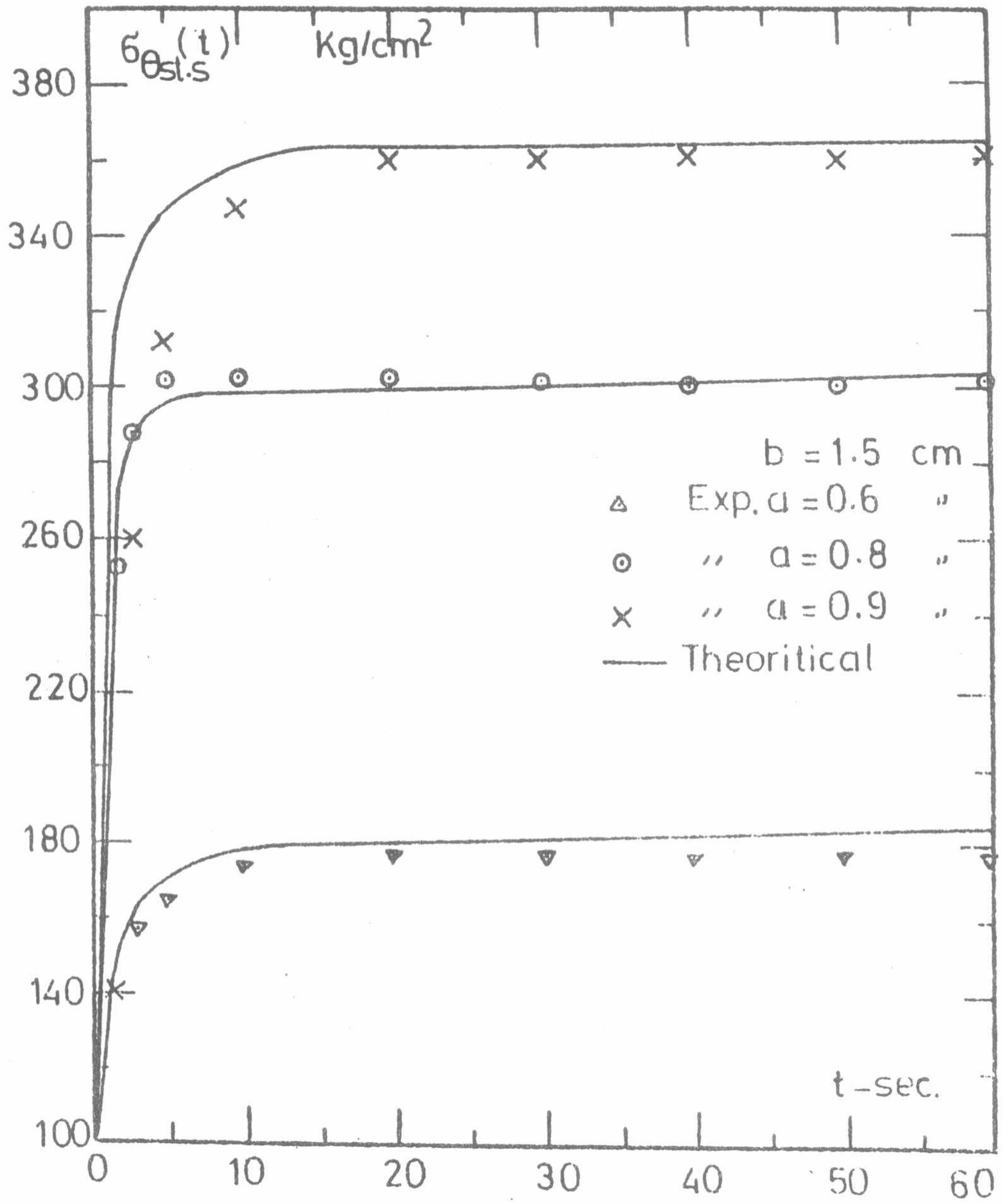


Fig.22 Effect of the PVC cylinder thickness on cirumferential stress in the steel shell and experimental points. Percentage error ranges from 0 to 3.