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Study of the Barreling of Copper Solid and Hollow Cylinders under Uniaxial Compressive Load

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K E Y W O R D S

Barreling, copper cylindrical, Aspect Ratio, uniaxial

A B S T R A C T

In this study, the effect of axisymmetric compression of cylindrical blocks of copper on diameter ratio, height reduction ratio and aspect ratio was noted. The effects of these non-dimensional parameters are very significant to the geometry of barreling throughout the process of plastic deformation of a cylinder under axial compression. The barreling effect was studied for solid and hollow copper cylindrical blocks having different dimensions. The relationship between the parameters was also studied. The practical results obtained were compared with some of the existing theories, and there was a good correlation of the results with these theories.

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1. Introduction

During most metalworking processes as rolling, forging, extrusion, …., etc., the surface tribology between the tool and the work affects the permanent deformation of the work, this can be clearly shown when a solid cylinder is axially compressed between two flat-faced parallel plates (dies). Friction between these plates and metal caused non-homogeneous plastic deformation and results in barreling or pollarding of the outer surface.

The pressure was required, and the effect of friction and dimensional parameters was studied by some investigators [1,2,3]. Some other workers paid attention to the flow of metal while pressing the cylinders between two flat plates [4,5]. The shape and dimensional changes were also studied [6.7] during the axial pressure of the solid cylinders. The following relation is given by Prof. Mehta [1] to estimate the pressure required for pressing of solid and hollow cylinders:

For solid cylinders:

$$\frac{P_{ave}}{\sigma_o} = 1 * \frac{2}{3} * \frac{m}{\sqrt{3}} * \frac{R_o}{T} \qquad (1)$$

While for hollow cylinders: $If \quad R_n \le R_i$

$$\frac{P_{ave}}{\sigma_o}=\frac{1}{1-(R_i/R_o)^2}\left[\begin{array}{l}\sqrt{1+\frac{1}{3}\left(\frac{R_n}{R_o}\right)^4}-\sqrt{\left(\frac{R_i}{R_o}\right)+\frac{1}{3}\left(\frac{R_n}{R_o}\right)^4}\\+\frac{2}{3\sqrt{3}}m\frac{R_o}{T}\left[1-\left(\frac{R_i}{R_o}\right)^3\right]\end{array}\right] \quad (2)$$

And if $R_i \le R_n \le R_O$

$$\frac{P_{ave}}{\sigma_o}=\frac{1}{1-(R_i/R_o)^2}\left[\begin{array}{l}\sqrt{1+\frac{1}{3}\left(\frac{R_n}{R_o}\right)^4}-\sqrt{\left(\frac{R_i}{R_o}\right)^4+\frac{1}{3}\left(\frac{R_n}{R_o}\right)^4}\\+\frac{2}{3\sqrt{3}}-m\frac{R_o}{T}\left[1+\left(\frac{R_i}{R_o}\right)^3-2\left(\frac{R_n}{R_o}\right)^3\right]\end{array}\right] \quad (3)$$

Where:

$$\frac{R_n}{R_o}=\frac{2\sqrt{3}*mR_o/T}{(R_o/R_i)^2-1}\left[\sqrt{1+\frac{\left[1+\left(\frac{R_i}{R_o}\right)\right]\left[\left(\frac{R_o}{R_o}\right)^2-1\right]}{2\sqrt{3}*mR_o/T}}-1\right] \quad (4)$$

The neutral radius of the hollow cylinder is an imaginary radius which remains unchanged during its deformation. Other theoretical analyses [8, 9] dealt with the effect of axial compression on the geometry of hollow cylinders which was found useful in determining the coefficient of friction between the die and the metal. Experimental work [7, 10] suggests that the curvature of the barrel shape found fits closely a circular or a parabolic arc.

The present investigation is aimed to establish a relationship between the radius of curvature of the barrel and the percentage deformation during Uniaxial Compressive testing. The major non-dimensional parameters which cover the geometry of barreling were studied, besides the effect of the pressure on these parameters.

Symbols and units

d_o & d_i :	Outside & Inside diameters of a hollow cylinder before deformation , mm
d_{if} :	Inside diameter of the hollow cylinder before deformation, mm
D &d :	Maximum outside & Minimum outside cylinder diameter after deformation, mm
h :	Height of the cylinder after deformation. (same as T), mm
h_o :	Height of cylinder before deformation, mm
m & σ_o :	Friction factor, no unit & Effective flow stress, MPa
R_i & R_n :	Inside radius & Neutral radius for hollow cylinder before deformation, mm
R_o :	Outside cylinder radius after deformation, mm
P_{avr} :	Average pressing pressure, MPa
P_{avr}/σ_o :	Relative pressing pressure, MPa

2. Experimental Procedure and Results

Hot rolled commercially pure copper (99.8/ Cu) of 0.24 KN/mm2 yield stress was used to prepare the cylindrical specimens for this study. Solid as well as hollow cylindrical specimens were machined to the diameter of do=25 mm and cut in five different heights (ho), ie.,10,20,30,40, and 50 mm. in hollow specimens, a uniaxial hole of 10 mm was made in each block as shown in Figure 1.

The specimens were pressed between two flat hardened steel dies using a hydraulic press. The change in pressure was noted by using a piezoelectric force transducer connected to a recorder and

voltmeter through an amplifier (Figure 2-C). The changes in the dimensions of the pressed cylindrical blocks were measured by a micrometer screw gauge.
The ring compression test method, which is widely used [3, 4] for determining the value of friction factor (m) for various forming processes, was used here for determining the friction factor (m) between the copper and the die. Five hollow copper cylindrical discs of 20 mm outer and 10 mm inner diameter having 4 mm thickness were pressed to different rations. Their change of dimensions was calculated and plotted (as dotted curve) on the calibration chart [3] as shown in (Figure 3), and the value of friction factor (m) was estimated as 0.15 by interpolation [3]. Four sets of both solid and hollow cylindrical specimens of four different aspect ratios (do/ho), each set consisting of five specimens, were pressed with different loads and dimensional changes were measured. Then diameter ratio (D/do) versus non-dimensional height (h/do) curves were plotted for different values of aspect ratios (ho/do) as shown in (Figure4-A and Figure 4-B). Also for different height reduction radios (h/ho), the relation between diameter ration (D/do) and aspect ratio (ho/do) are shown in (Figure 5-A and Figure 5-B), for solid and hollow specimens respectively.

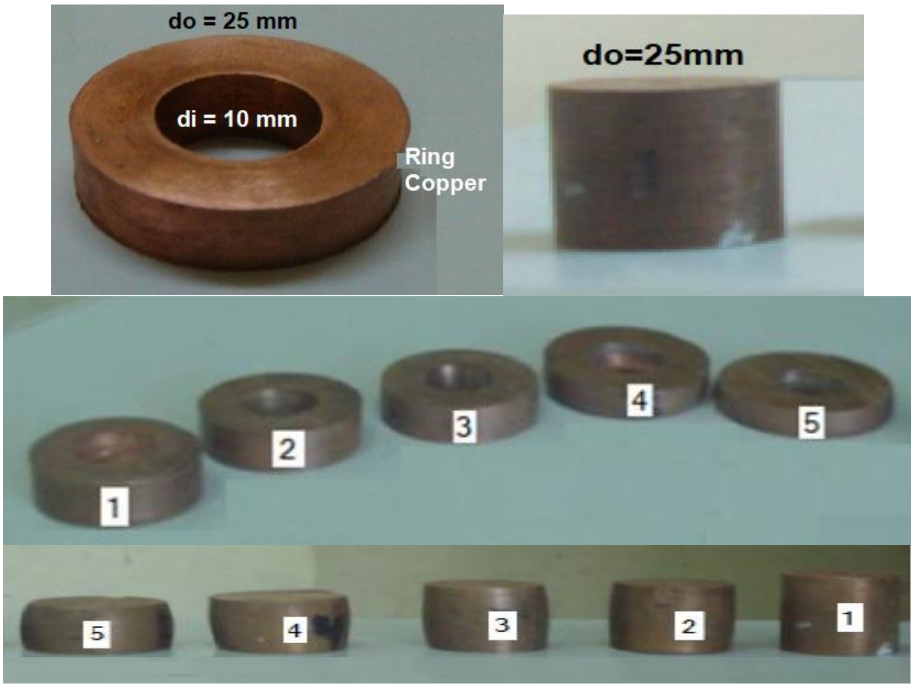
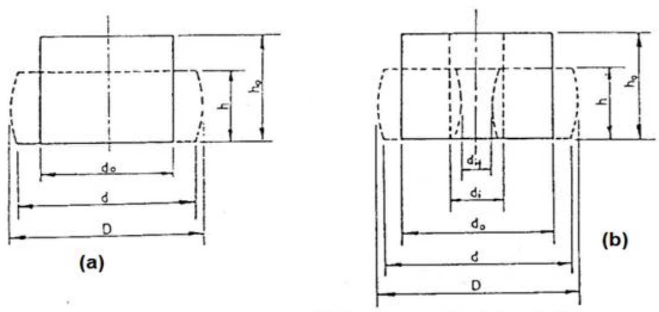


Figure 1: Cylindrical Specimens (Solid and Hollow)



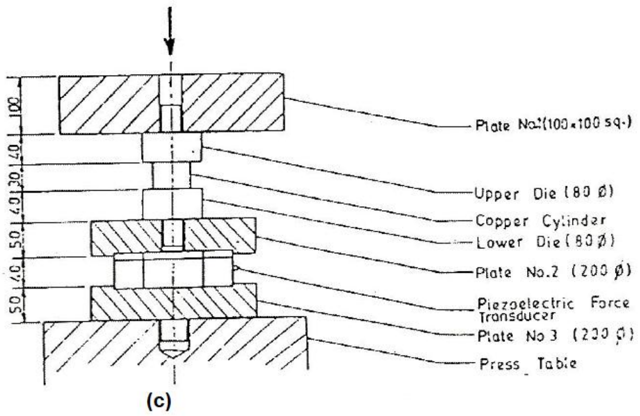


Figure 2: geometer of Barreling for Solid and Hollow Cylinder with the Setup used [3] (a) Deformation of Solid Cylinder, (b) Deformation of Hollow Cylinder, (c) Experimental Setup for Pressing of Cooper Cylinder

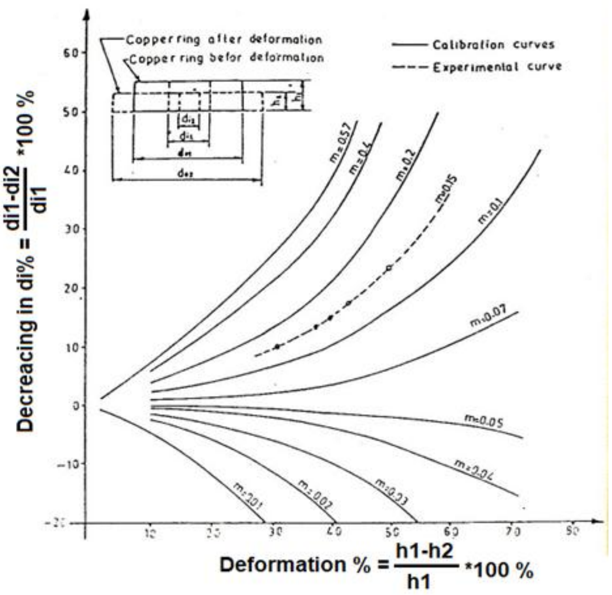
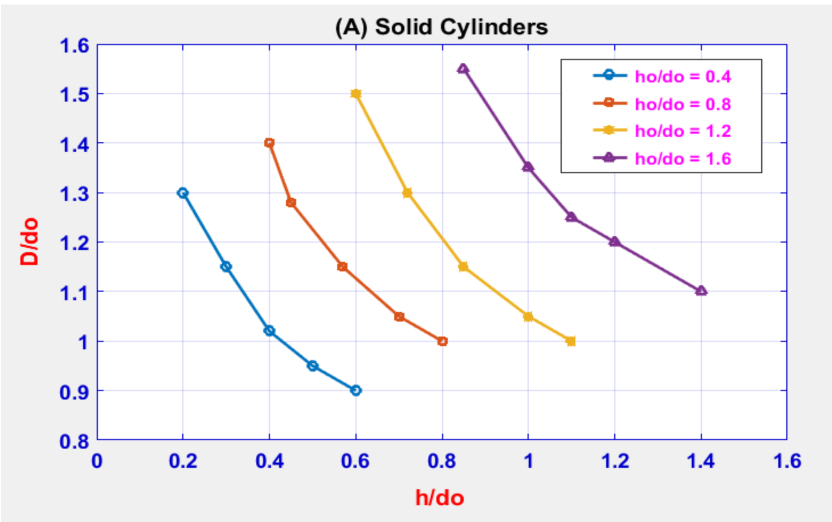


Figure 3: Experimental Curve for Friction Factor Evaluation using the calibration chart for the Ring Test [3]



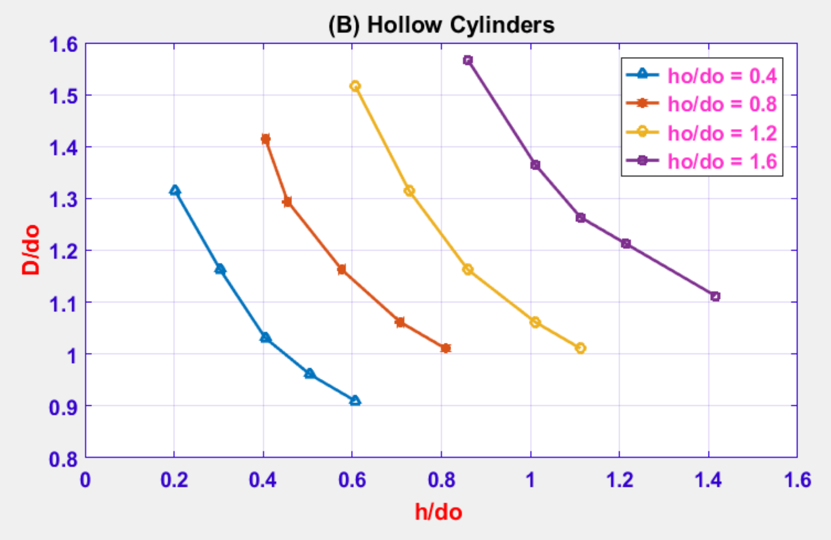


Figure 4: Experimental Variation of Diameter Ratio (D/do) with Respect to Non-Dimensional Height (h/do) for Different Aspect Ratios (ho/do) {A-for Solid Cylinder and B-for Hollow Cylinder}

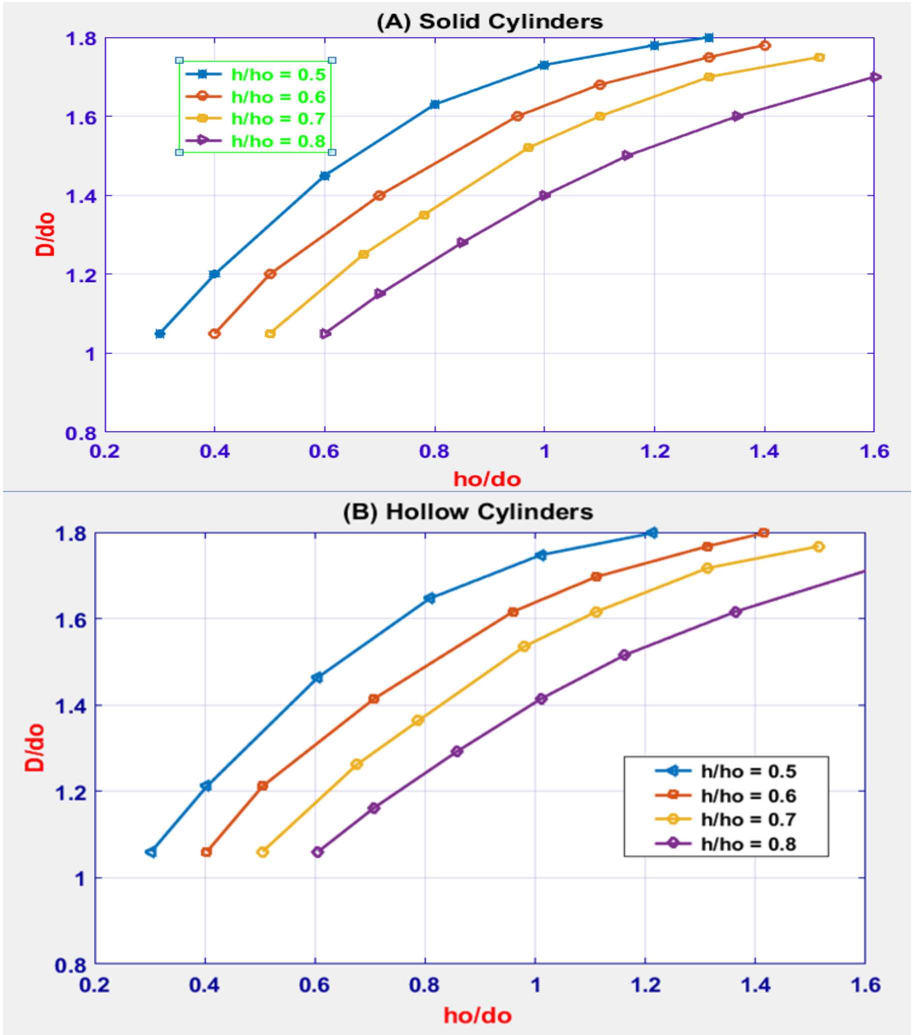
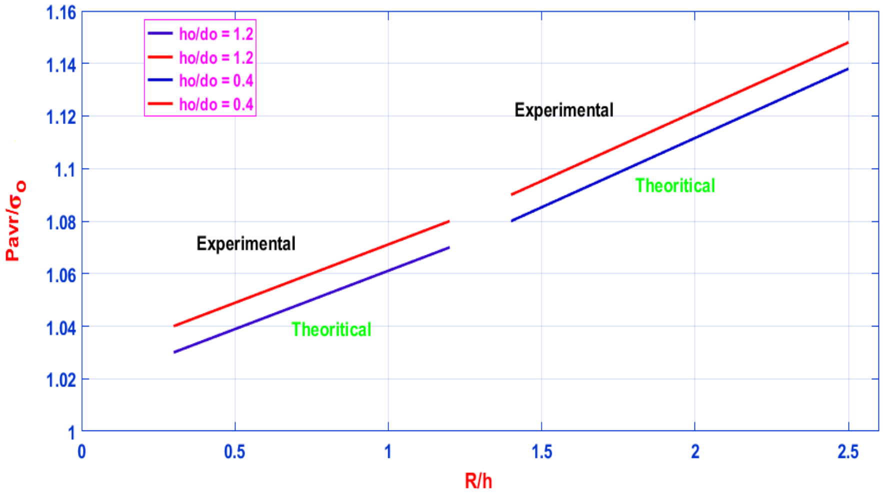


Figure 5: Experimental Variation of Diameter Ratio (D/do) with Respect to Non-Dimensional Height (h/ho) for Different Aspect Ratios (ho/do) {A-for Solid Cylinder and B-for Hollow Cylinder}

The average pressure ratio (P_{are}/σ_o) observed for each case was compared with the theoretical values as shown in Figures 6 and 7 for discrete and hollow samples respectively.



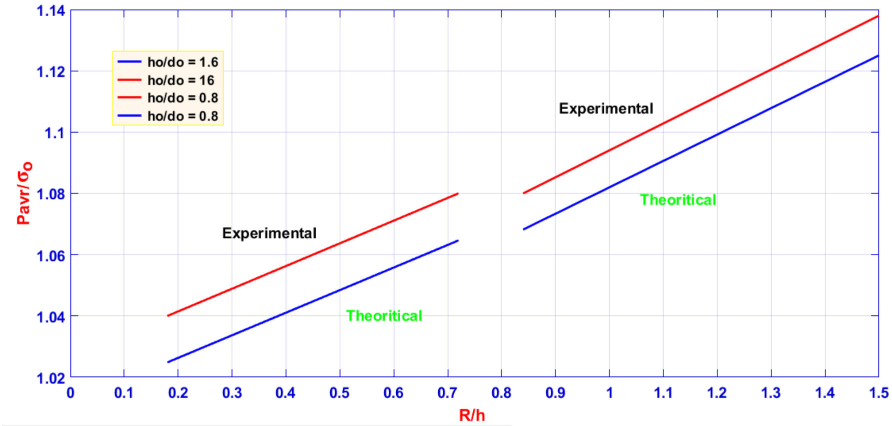
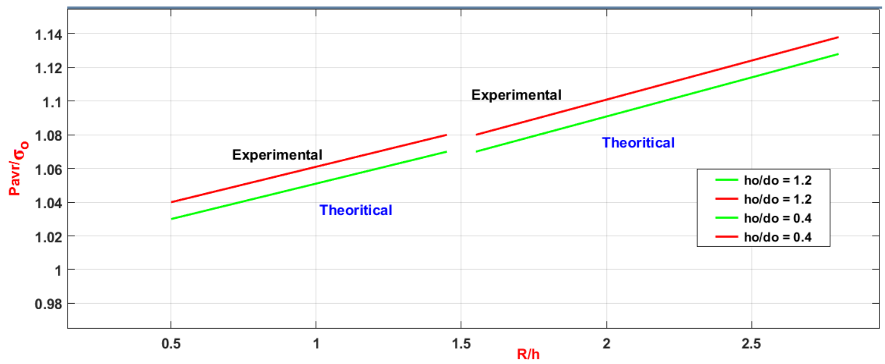


Figure 6: Variation of Pressure Ratio (P_{avr}/σ_o) with Respect to Radius/Thickness Ratio (R/h) for Different Aspect Ratios (ho/do) for Solid Cylinder



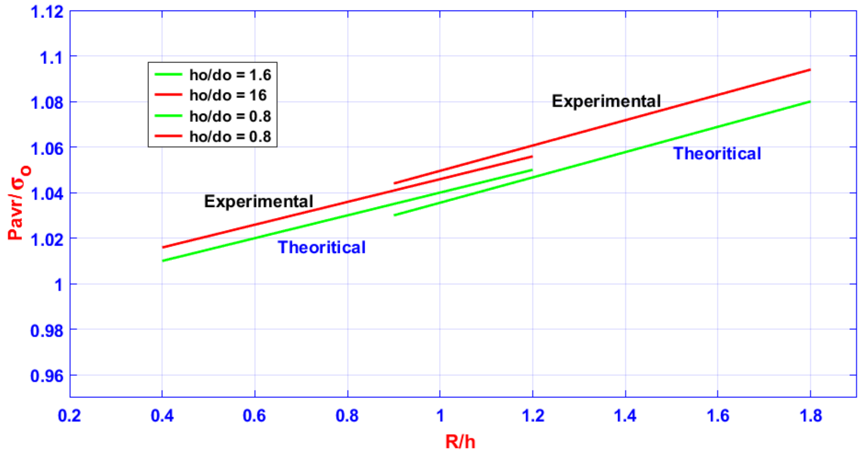


Figure 7: Variation of Pressure Ratio (P_{avr}/σ_o) with Respect to Radius/Thickness Ratio (R/h) for Different Aspect Ratios (ho/do) for Hollow Cylinder

3. Discussions

Figure 4 illustrates the change of D with respect to hovering arrange of aspect ratios (ho/do) between 0.4 and 1.6. All the variables are non-dimensional. It can be observed from the slopes of the curves in (Figure4) that for large aspect ratio (ho/do) as 1.6, the increase in the maximum barrel diameter D is less sensitive to the shortening of its height (h) as compared with short cylinders with aspect ratio such as 0.4. (Figure 5) shows the increase in barrel diameter with the shortening of its height. It shows for different height reduction ratios (h/ho) that there is an increase in diameter ratio (D/do) with respect to aspect ratios (ho/do). The relative pressure required experimentally for barreling is plotted against the thickness ratio (R/h) for barreling is plotted against the thickness ratio (R/h) in (Figures 6 and 7) for different aspect ratios. These experimental results are compared with theoretical results using equations 1, 2 and 3 for solid and hollow cylinders.
Experimental and theoretical results shown (Figures 6 and 7) are in agreement in that the required relative pressure (P/σo) increases as the thickness ratio R /h increases. For different ho/do values. The increase of pressure required by the increase in thickness ratio is attributed mainly to the increase in plastic flow needed. As a light deviation between experimental and theoretical results as shown in (Figures 6 and 7) is due to the assumption of the constancy of σo and m values during the process. Actually the value of o increases due to work hardening and the actual value of m depends on many factors such as the surface finish of each cylinder.
From this experimental work it was observed that the flow of metal in the flow of metal in the exterior surface of the hollow cylinder was greater than in the in the interior surface.

4. Conclusions

From the present investigation the following conclusions are drawn:
For each aspect ratio (ho/do), there is an increase in height ratio (h/do) for any decrease in diameter ratio (D/do). This is true for solid and hollow cylinders.
At every height ratio (h/do) there is an increase in aspect ratio (ho/do) for any increase in diameter ratio (D/do), for solid and hollow cylinders.
The trends found in this investigation (Figure 5 and Figure 6) show agreement with the theoretical prediction.
The slope of the curves of (D/do) versus (h/do) decreases (Figure 3) with an increase in (ho/do).

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