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Determination of Hoop Compressive Strength of Ceramic Cylinder by experimental method

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Abstract:-

In this study, experimental technique was utilised to find hoop compressive strength of ceramic cylinder. Two steel half sleeves were enveloped on a ceramic cylinder and they were tightened by 4 bolts. The bolts were gradually tightened using a torque wrench and the torque on bolts at which failure occurred is noted down. Based on the torque, using existing literature bolt loads were found. This load equalises external pressure multiplied by the projected area of cylinder and the same is equated to the resistance offered by the cylinder walls and there by the hoop compressive strength of the ceramic cylinder is found. This experiment was carried out, to decide on the design hoop compressive stress. Based on the design hoop compressive stress the pre-compressed ceramic cylinder of a proposed high efficiency IC ceramic engine, will be designed.

Keywords: Pre-compression, Pre-stressing, Ceramic engine, IC engine, Diesel engine.

IINTRODUCTION

It is important to save fossil fuels as much as possible as they are depletable and may not last for long. Especially the liquid fuel like diesel and petrol may last for next 60 years only if they are used at the present rate. Hence, it becomes necessary to boost up the mileage of big trucks, Lorries and buses that consume 80% of the total diesel imported. Up gradation to ceramic engines to is the best possible solution to boost up the mileage of these big vehicles. Ceramic material can withstand the high temperature possible in the high efficiency engines, but they are very weak in withstanding shock, vibration and hoop tensile stress that are produced during the various cycles of operation of the diesel engines. Hence in this project work it was first decided to experimentally find out the hoop compressive stress. Based on the ideas found in the literature (Ref 1-8) on pre stressed concrete, it was decided that the ceramic cylinder that was planned to be used as IC engine cylinder was thought of to be pre compressed. On pre compression hoop compressive stresses will be introduced even before the start of the engine and as the engine load increases, the internal pressure caused inside the cylinder due to explosion of fuel and compression of air will induce enormous hoop tensile stresses and part of the same will be offset by the hoop compressive stresses produced by initial pre compression. Due to these reasons, the thickness requirement will come down drastically thus reducing the press tonnage required to manufacture the ceramic cylinder and the cost of the cylinder price will be brought down heavily. Also the system itself will become very compact. Thus in this project the first step required is to establish hoop compressive strength of the ceramic cylinder. A test set up was fabricated and experimentally the hoop compressive strength of ceramic cylinder was determined. Yawing, et.al. A compressive residual stress in the surface layer will greatly improve the flexural strength and crack growth resistance of ceramic components. XJ Yang et.al.,. In order to investigate the relationship between torque and preload after tightening the bolts by using a torque wrench, that apply a set torque, and the bolts are applied with a particular tensile load. Graphs are available to read the tensile load on the bolts according to the torque applied. The effect of lubrication between nut and bolt also are taken care of in the graphs drawn on the load vs. Torque. Another graph on load vs. torque gives the pre-tightening load without lubrication. Thus for both lubricated and un-lubricated condition between the bolt & nut the pre-tightening load can almost be exactly predicted.

MATERIAL USED

Alumina with over 99.6% purity is used for the ceramic cylinders tested in this work. The ceramic material used for the cylinder is hard and brittle. The corresponding properties for the cylinder material are given in table-1.

Ceramics

- Ceramics has been in the limelight, to be applied in Engines, for various reasons which are highlighted as below
- Good thermal insulator
- Wear resistant
- ❖ Engine parts can be made of Ceramics
- ❖ Existing engine parts can be quoted with Ceramics
- ❖ Reduction in friction
- ❖ Increased effective efficiency,
- ❖ Increased thermal efficiency
- ❖ Improved reliability,
- ❖ Smaller size,
- ❖ Lighter weight,
- ❖ Decreased the heat removed by the cooling system,
- ❖ The first start of engine on cold days will be easier.

Properties of ceramic material (Al_2O_3)

Table: (1)

Chemical formula	**Al_2O_3**
Molar mass	101.960 $g.mol^{-1}$
Appearance	White solid
Odor	Odourless
Density	3.987g/cm^3
Melting point	2,072^{o}c

EXPERIMENTAL WORK

Ceramic cylinders were compressed by using two half steel sleeves clamped by four bolts. These bolts were applied equal torque using a torque wrench. The torque set in the torque wrench was gradually increased to find out the breaking torque on the bolts, so that the ceramic cylinder begins to fracture. A little lower value than the breaking torque on bolts is the maximum safe torque that can be applied on bolts and for this torque the pre tension on the bolts was estimated by using literature (Ref.). Fig. (1).

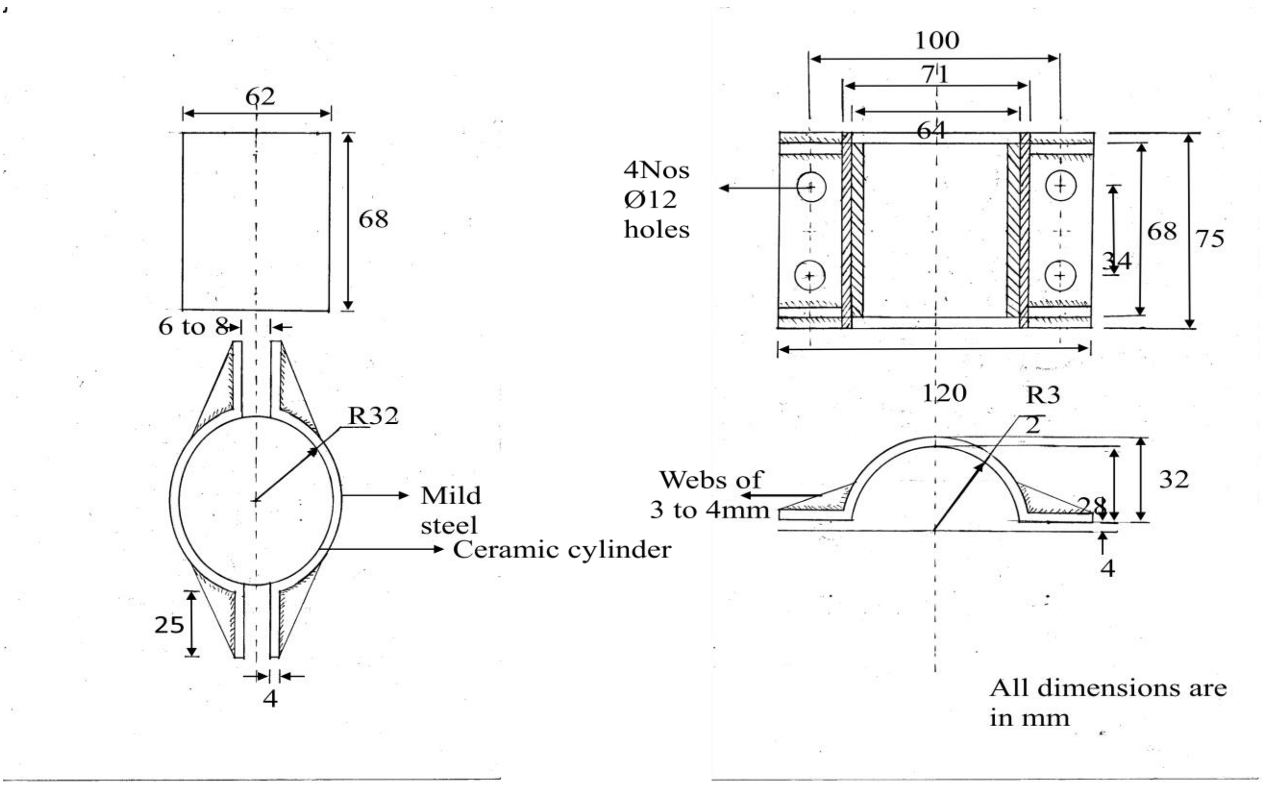


Fig. 1. DepictsTest Setup For Determination of Hoop Compressive Stress In Ceramic Cylinder

With the help of the pre tension on the bolts estimated the equivalent external pressure applied on the ceramic cylinder is found. By utilizing the equivalent external pressure estimated on the ceramic cylinder, the maximum hoop compressive stress that can be withstood by the ceramic cylinder is estimated. This all arrangement part and shown in fig. (2) & (3).

Fig.2. Cylinder Arrangement Parts

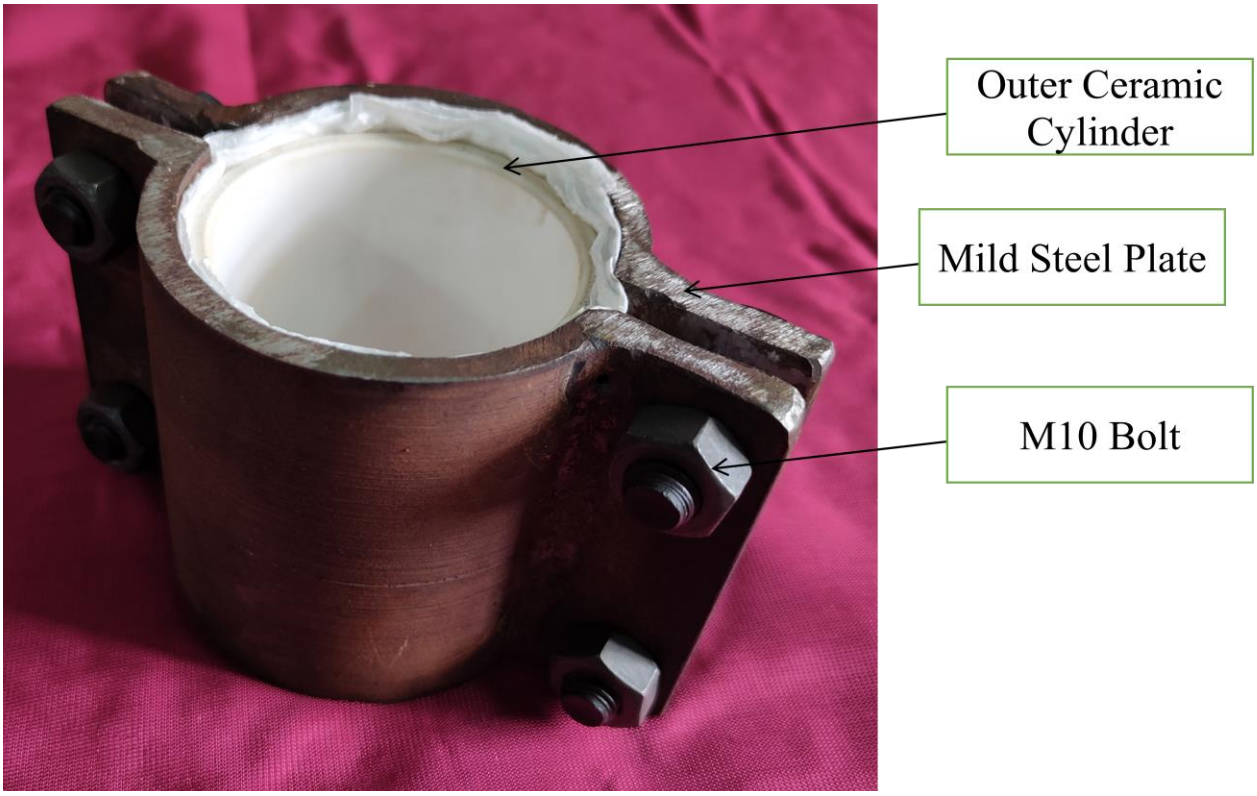
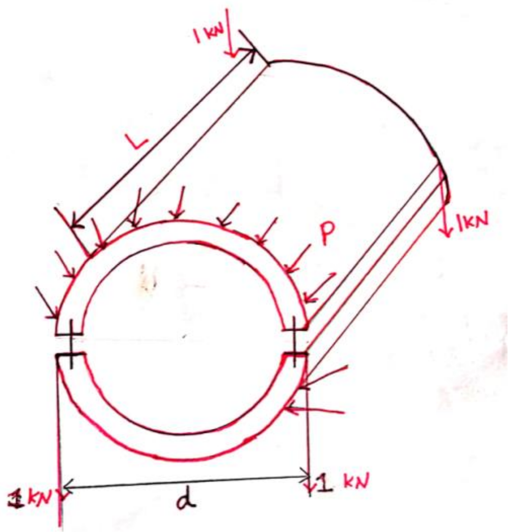


Fig.3. Establishment of Compressive Strength of Ceramic Cylinder Arrangement

(a) CALCULATION OF EQUIVALENT EXTENAL PRESSURE APPLIED ON CYLINDER DUE TO BOLD LOAD



Pre Load on One Bolt = 1 KN

= 1000 N

Pre Load on 4 Bolts = 4 KN

= 4000

To Find:

1. Equivalent External Pressure on Cylinder (Pc).
2. Design hoop Compressive Stress (σ_c).

Mean Diameter of Cylinder = $\frac{OD+IDOD+ID}{2 \qquad 2} = \frac{do+dido+di}{2 \qquad 2}$

$d_{mean} = \frac{61.5+5261.5+52}{2 \qquad 2}$

d_{mean} = 56. 75 mm

Length of Cylinder, L = 67 mm

Total Bolt Load = $d_o \times L \times Pc = 4000 \times L \times Pc = 4000$ N

Where,

do = Outer Diameter of Cylinder, mm,

L = Cylinder length, mm,

Pc = External pressure applied on ceramic cylinder due to bolt loads, N/mm^2,

$61.5 \times 67 \times Pc = 4000 \times 67 \times Pc = 4000$

$Pc = \frac{4000 \qquad 4000}{61.5 X 6761.5 X 67}$

= 0.97 N /mm^2

≃ 1 N/mm^2

≃ 1 Mpa

≃ 10 Kgf/cm^2

(b) CALCULATION OF HOOP COMPRESSIVE STRESS AT BREAKING TORQUE ON BOLTS

$2t \times L \times \sigma_c = 4000$

Where,

t= Thickness of Cylinder = 4.3 mm,

L= Length of Cylinder = 67 mm,

σ_c = Hoop Compressive Stress, N/mm^2,

Total Bolt Load = 4000 N.

$\sigma_c = \frac{4000 \qquad 4000}{2\times4.3\times672\times4.3\times67}$

= 6.97 N/mm^2

= 6.97 Mpa

$\sigma_c \simeq$ 70 Kgf/cm^2

Design Hoop Compressive Stress = 50 Kgf/cm^2

RESULTS & DISCUSSION

While testing **cylinders 1 & 2**shown in fig. (4), (as per table) all the 4 bolts were inserted from one side only and the bolts were NOT tightened using torque wrench, in diagonal sequence. Cylinder 1 broke at **18 N-m**& cylinder 2 broke at **14 N-m**. These tests on cylinder 1&2 were rejected, mainly because; the bolts were not tightened in diagonal sequence.

While testing **cylinders 3, 4 & 5shown in fig. (5),** (as per table) the 4 bolts were tightened using torque wrench in diagonal order. And one set of diagonal bolts were inserted in one direction and the other set, direction wise opposite. Cylinder 3 broke at **10 N-m**, cylinder 4 broke at **12 N-m** and cylinder 5 broke at **10 N-m**. And the average [9 N-m approx] of these three results was taken as the breaking torque on bolts.

TABLE I

Test condition for hoop compression test value

Inner dia = 52 mm

Cylinder	Height in mm	Outer dia in mm				Thickness in mm				Breaking torque on bolts in N-m	Possible maximum torque on bolts in N-m
		d1	d2	d3	avg	t1	t2	t3	avg		
1	67	61.20	61.50	61.90	**61.53**	4.36	4.36	4.32	**4.34**	20 N-m	18 N-m
2	67	61.44	61.48	61.78	**61.56**	4.30	4.30	4.32	**4.30**	16 N-m	14 N-m
3	67	61.66	61.50	61.62	**61.59**	4.32	4.40	4.30	**4.34**	10 N-m	8 N-m
4	67	61.38	61.24	61.50	**61.37**	4.30	4.28	4.32	**4.30**	12 N-m	10 N-m
5	67	61.74	61.32	61.74	**61.60**	4.32	4.14	4.32	**4.26**	10 N-m	8 N-m

CERAMIC CYLINDER IN BREAKING CLAMPING LOAD

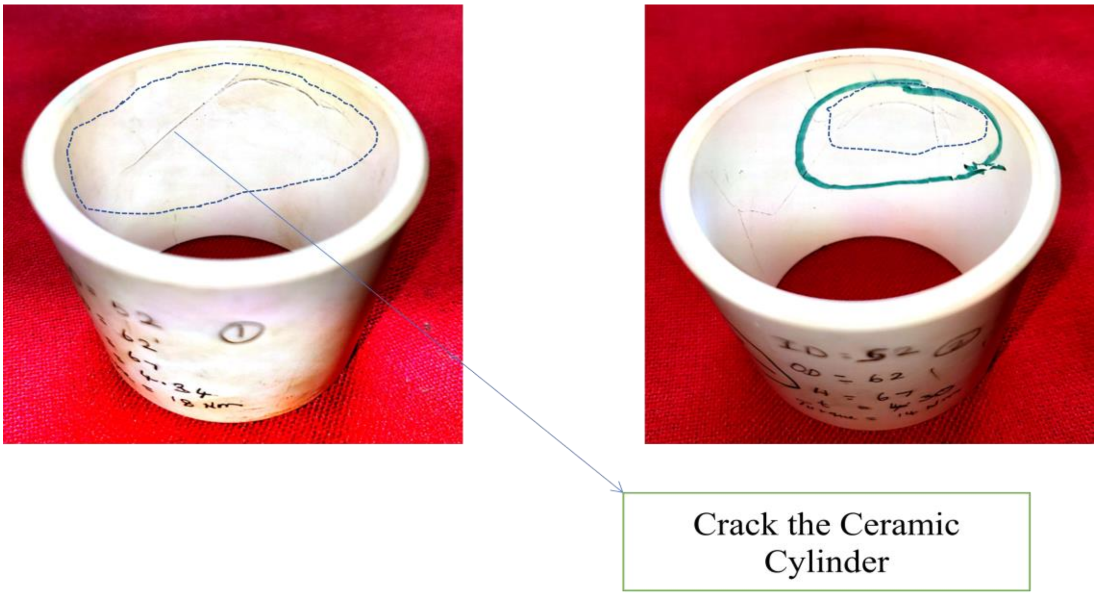


Fig.4. Rejected ceramic cylinder

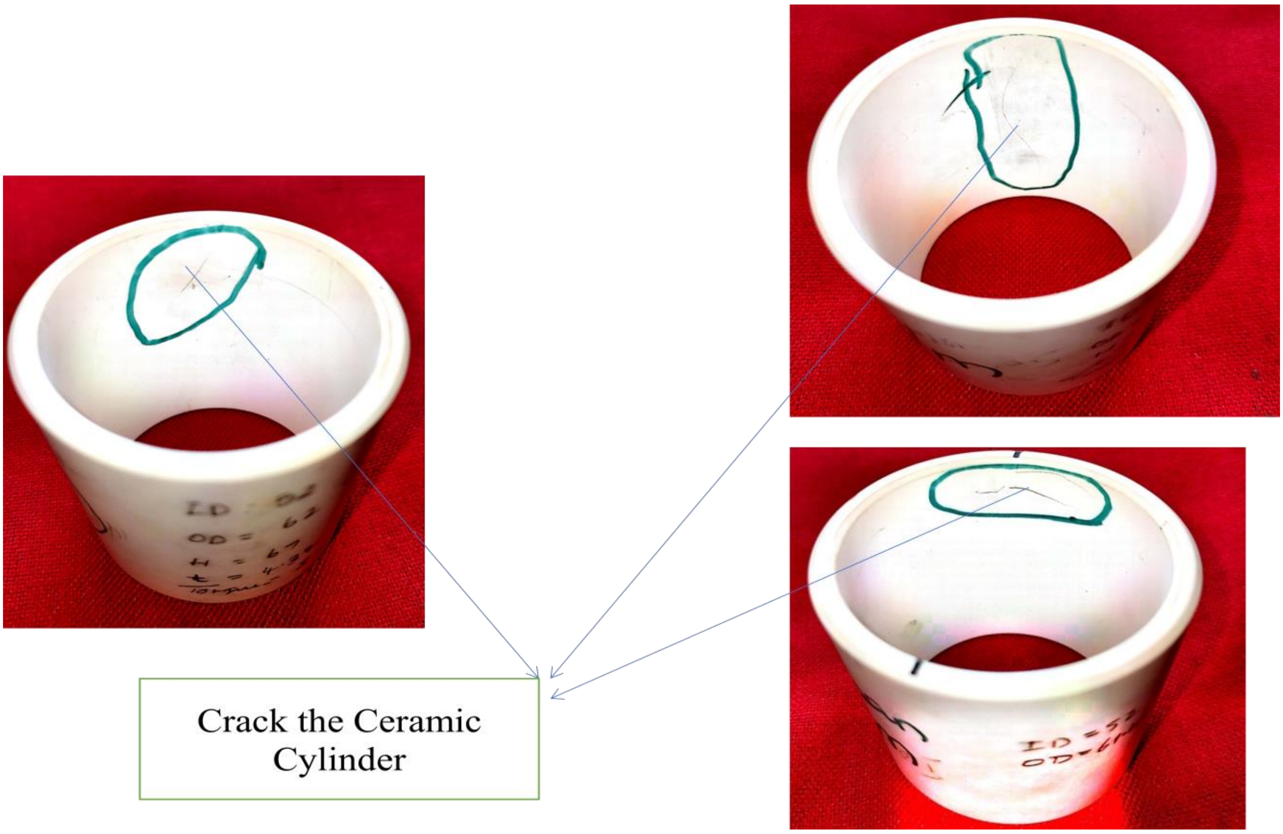


Fig.5. Cracked Ceramic Cylinder

CONCLUSION

Maximum safe clamping torque on bolts was taken to be 9 N-m approximately. Based on this safe clamping torque, the design hoop compressive stress will be decided. Based on the hoop compressive stress, the ceramic cylinder of a proposed high efficiency ceramic IC engine will be designed.

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