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Development of a Low-Cost Compression Device for Ceramics Materials

Md. Mostafa Kamal[1,*], *Mir Imran Bin Samad*[1], *Md. Nurul Islam*[1]
[1] Department of Mechanical Engineering, Rajshahi University of Engineering & Technology, Rajshahi-6204, BANGLADESH

ABSTRACT

Ceramics are naturally brittle; therefore, their ability to withstand compression is critical for practical uses. Consequently, a high-precision universal testing machine should be used to evaluate their mechanical properties, particularly their compressive strength. However, a high precision compression device is not widely available. Therefore, in this current study, we have designed and built a compression device using only locally sourced materials. A simple gear train was used for driving the machine, which reduced the cost and helped get the ASTM recommended feed rate for compression testing. Along with complexity and cost, it is very difficult to obtain the optimum feed rate for compression testing in the system with a hydraulic or pneumatic drive. The building blocks for the compression device are the Arduino, S-type load cell, TCRT sensors, simple gear train, and DC motor. The geometry of the compression device has been developed using SOLIDWORKS, and stresses developed in different mating parts of the compression device have been observed using ANSYS. For validation, we compared the obtained results to those of the Universal Testing Machine (WANCE, China) under the same operating conditions. With MATLAB interfacing, the developed compression device can plot a real-time load vs. deflection graph as well as an excel file containing the values of load and deflection. The compressive strengths of the plastic wood and lanthanum manganite samples were found to be 6.78 MPa and 39.91 MPa, respectively, whereas the value of the corresponding compressive strength from the Universal Testing Machine was 11.34 MPa and 58.45 MPa under the same operating conditions at low deformation resolution. The main advantages are its portability and inexpensive manufacturing costs (USD 530), which can be reduced by at least 20 to 30% by optimizing the size of the parts used in the design.

Keywords: Compression device, Ceramics materials, Gear train, Universal testing machine, Arduino

1. Introduction

Ceramics are one of the most promising materials nowadays in the field of materials science and engineering. Ceramics have proven to be an invaluable material in industrial and high-temperature applications such as refractory bricks, coatings over turbine blades, furnace walls, etc. Such a variety of applications emphasizes the importance of understanding the mechanical behavior of ceramic materials. Generally, the mechanical behavior of the ceramics has been investigated in terms of bending strength, compressive strength, fracture toughness, and diametral tensile strength [1-4]. The behavior of ceramic materials in compression is particularly important since ceramics have a compressive strength that is around ten times higher than their tensile strength. The universal testing machine can perform tensile tests as well as compression tests. But compression tests of ceramics are a real challenge with ordinary universal testing machines. Because of extreme brittleness, the feed rate must be within a tolerable limit. Brittle fractures typically occur with little deformation and rapid crack propagation. There are many standard testing methods are available, but ASTM standards are mostly preferred by materials scientist and Engineers. The ASTM C1424 standard specifies the requirements for ceramics testing [5]. An extremely low strain rate is required for compression tests on ceramics. Generally, it is in the order of 2×10^{-5}/s [6]. The feed rate of the tester should be very low, which is hardly possible with an ordinary universal testing machine. Therefore, in this current study, we have designed and built a compression device using only locally sourced materials as per the requirements of ceramic material testing. In the developed electromechanical compression tester, a 4000 N maximum load can be produced with two adjustable plates, capable of producing a feed rate of 0.5 mm/min. The main factor in avoiding the locally available linear actuator in the local market is cost. Typically, an electromechanical testing machine consists of a load source, a controller to maintain feed rate, a drive system, and a mechanism to move the direct pressing head up or down. In this current work, a simple gear train along with a power screw is used as a power transmission gateway from the DC motor. A typical flow chart of power transmission and data acquisition for the developed compression device is shown in Fig.1.

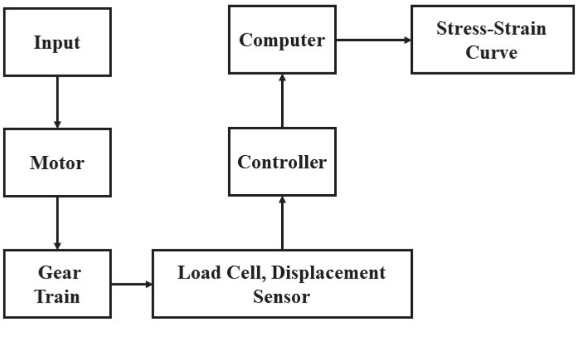

Fig.1 Block diagram of LCCD setup.

2. Methodology

Cast iron is the primary material for the fabrication of the parts of the compression device, which was

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* Corresponding author. Tel.: +88-01789973755
E-mail addresses: mostafakamal2048@gmail.com

sourced from the local market in Rajshahi. The linear actuator was avoided because it had a higher feed rate than was recommended for ceramic material testing. Most of the researchers used 10×3×3 mm samples for compression tests of ceramic materials which specifies the dimensions of the compression tester [7]. The newly developed compression tester was powered by a DC motor. Forward or backward movement of the compression plate was controlled by reversing the polarity of the DC motor with the help of a low-tension switch. The compression plate was moved through a lead screw, which was designed and manufactured locally. A gear train with a speed ratio of 3.14 was used in the developed compression device. Power from the motor was transmitted to the compression plate through a simple gear train and lead screw. The load on the sample was measured by the S-type 500 kg load cell attached to the compression plate. The deflection of the sample from its initial position was measured with a TCRT sensor attached to the S-type load cell. The load cell was calibrated with the standard weight, and the TCRT sensor was calibrated with the standard dimensions with the help of a scale. The designed load of the developed low-cost compression device was 4000 N. The conceptual design of the developed compression device is shown in Fig.2.

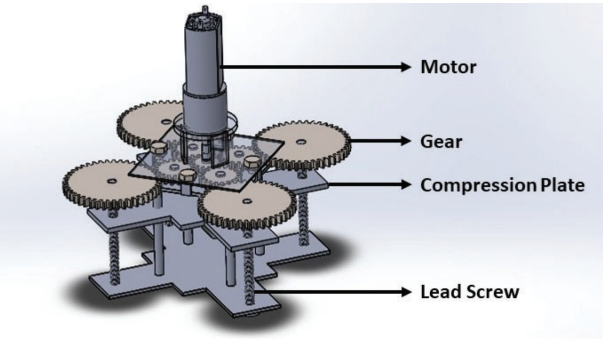

Fig.2 Conceptual drawing using SolidWorks.

The Arduino UNO R3 was used as a controller for the newly developed low-cost compression device. Data from the load cell and TCRT sensor was collected through an Arduino, which was connected to a computer. With MATLAB interfacing from the dataset, a real-time load vs displacement curve was generated as well as an excel file containing the values of load and displacement. From the load vs displacement curve, a stress-strain curve can be generated.

2.1 Design

A key part of the newly invented inexpensive compression device is the lead screw. According to standard design approaches, the lead screw was designed [8]. The major diameter of the lead screw was 0.75 inch, and the tread per inch was 11. The invented compression device consists of four identical lead screws, through which the compression plate moves. Gears with varying tooth numbers were chosen for the fabrication of the power transmission mechanism of the developed compression device, which was available locally. We can calculate the gear train's speed ratio that was employed to create the speed reduction mechanism of the developed compression device by dividing the number of teeth in the driven gear by the number of teeth in the driver gear. For the developed compression device, the tooth numbers for the drive and driver gears were 44 and 14, respectively. Therefore, the motor's speed was slowed down. For this study, we used a square compression plate with the following dimensions: 15.24×15.24 cm. The lead screw was fed into the thrust bearing from one end. To ensure that the compression device moves in a smooth, even motion, a set of collars was included in the assembly. In ANSYS, equivalent von Mises stresses were seen in the different parts of the device that fit together when the assembly transmitted power at high speed, as shown in Fig. 3.

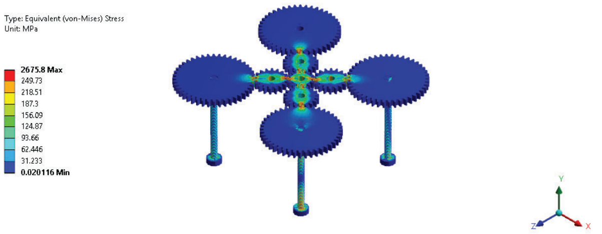

Fig.3 Equivalent (von-Mises) stress in power transmission assembly.

Actually, the developed stresses as well as the deflection are much less than the simulated ones because of extra support as well as proper lubrication.

3. Experimental Setup

The actual setup of the developed compression device is shown in Fig.4 and in Fig.5. The conceptual framework differs from the actual implementation due to the specialized cases.

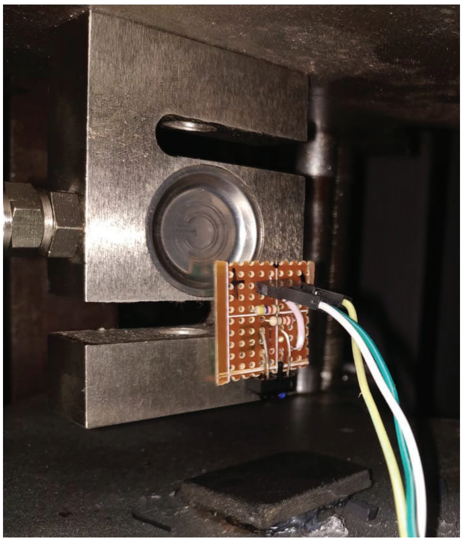

Fig.4 S-type load Cell and TCRT Sensor.

To accommodate the large DC motor employed in the device's design, the modification has been made from the conceptual design.

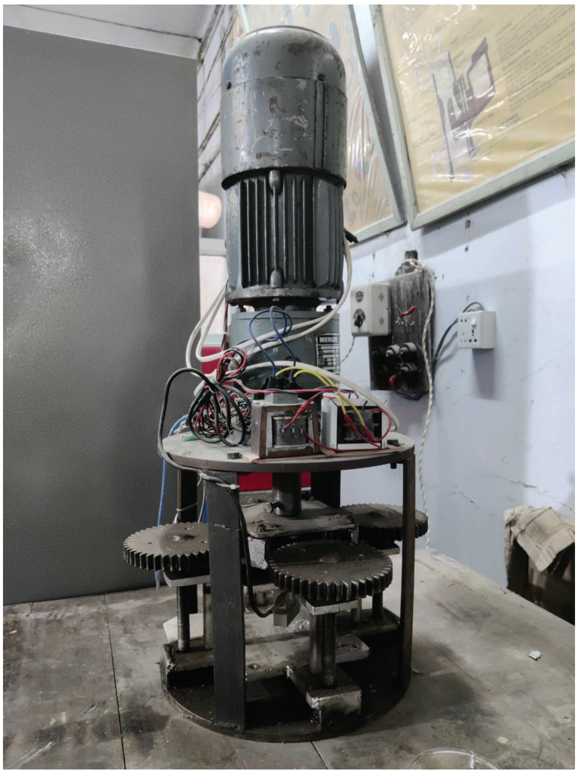

Fig.5 Actual Setup of developed compression device.

4. Results and Discussions

The compressive strength of a ceramics sample can be determined by dividing the load at break by the corresponding cross-sectional area of the standard sample. A standard sample of plastic wood and self-made lanthanum manganite was prepared according to the ASTM standard. Under the same atmospheric conditions, both the plastic wood and lanthanum manganite samples were tested in universal testing machines and the developed compression device. The values of the compressive strength of the plastic wood sample obtained from the universal testing machine (Wance, China) and the developed compression device were 6.78 MPa and 11.34 MPa, respectively. The test result of a lanthanum manganite sample from the developed device and universal testing machine is shown in Fig. 6 and Fig. 7, respectively. The corresponding values of the compressive strength of ceramics samples are 39.91 MPa and 58.45 MPa. There is a difference in the values that may be due to a calibration error in both the load cell and the TCRT sensor. Fig. 8 depicts a comparison of the stress-strain curves produced by the universal testing machine and the newly created compression device for a self-made sample of lanthanum manganite. The variation in the result was caused not only by machine error but also by the non-homogeneity of the ceramics sample. In comparison to the universal testing machine, the trend of the load vs. deflection curve in the developed compression device is quite similar. The entire cost to manufacture the device was approximately $530 (this price includes the cost of the raw materials, sensors, motor, electrical accessories, and others). It is possible to lessen both backlash inaccuracy and self-weight by switching to a plastic gear that was made using 3D printing technology instead of a metal one. As a result of the size of the motor used, the aesthetic value of the intended compression device is diminished. Because of the use of locally available accessories, this has occurred.

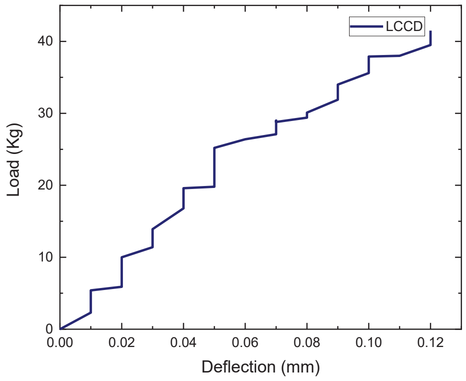

Fig.6 Load vs Deflection curve in LCCD.

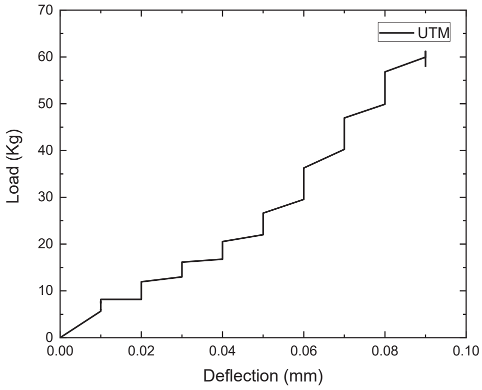

Fig.7 Load vs Deflection curve in UTM.

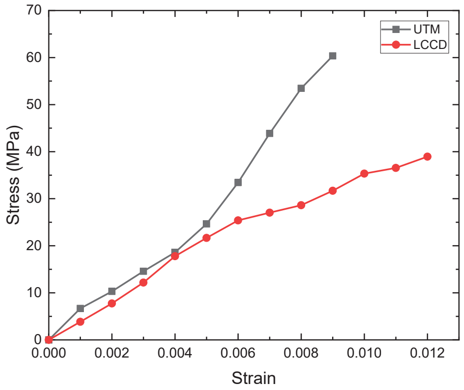

Fig.8 Comparison of Stress-Strain Curve.

The new compression device has a few drawbacks, including a size restriction (testing samples must be between 10 and 16 mm long) and the inability to detect sample breakage automatically. Data will be more accurate if the load cell is calibrated more precisely. The use of a precise distance-measuring sensor may be used in future research and development. Adding a smart rupture detection system to the manufactured compression device would make it more accurate and reliable. Using a suitable fixture, the developed compression device can conduct a flexural test of the ceramic material. The developed compression device can perform the diametral tensile test of ceramic material without any external fixtures.

5. Conclusions

The total cost of fabrication of the compression device was approximately 530 USD, which is quite low as compared to the available universal testing machine. By optimizing the size of the motor as well as the gear train, the cost of fabrication can be reduced by at least 20 to 30%. Portability is the most important feature of the newly developed, low-cost compression device. For future development, an electronic system of feed reversal mechanisms may be employed to obtain easy operation of the developed compression device.

6. References

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NOMENCLATURE

ASTM: American Society for Testing and Materials
MPa : Megapascal
USD : United States Dollar
LCCD: Low Cost Compression Device
UTM : Universal Testing Machine