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# Development and assessment of a hand operated ice crusher for immediate fish preservation in remote areas of Bangladesh

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ABSTRACT

Ice is commonly used to preserve fish, but ice crushers are not always available in rural and remote areas of Bangladesh. A low-cost hand-operated ice crusher was developed in the Department of Farm Power and Machinery at Bangladesh Agricultural University. The machine yielded a throughput capacity of 21.6 kg $min^{-1}$ with an average loss of 13.1%. The average time to crush a 10.6 kg ice block was 21.6 seconds. The total deformation, strain energy, maximum shear stress, and structural error were estimated as 0.0046 mm, 0.0031 MJ, 28 MPa, and 0.0025 MJ, respectively, for a single spike of the crusher. The average revolution per minute of the crushing cylinder was 493.6, with a maximum value of 634.7, and the maximum vibration frequency was 10.7 Hz. The maximum noise level during crushing operation was 92.9 dB, which was within the acceptable range. The machine's ergonomic assessment after operation yielded a satisfactory result. On average, the operators' blood pressure (systolic and diastolic), pulse rate, and respiration rate were 138.4 and 74.2 mm (Hg), 105.4 per minute, and 20 per minute, respectively. The results of the performance evaluation indicate that the device appears to be a suitable input for marginal fish farmers with inadequate access to electricity

**Keywords:** Crushing capacity, ergonomics, finite element analysis, fish preservation, marginal farmer

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## 1 Introduction

Bangladesh is a small country standing at the 92nd position in size, having only 148,460 $km^2$ area (Hasan et al., 2016). However,the country is fortunate to have an extensive inland open water resource in the form of wetlands, natural depressions (haors and beels), reservoirs, canals, rivers, and estuaries covering 4.7 million hectares (Shamsuzzaman et al., 2017). These water resources are the primary source of the country's critical protein supply. As Bangladesh is predominantly an agro-based country, the role of the fisheries sector in the national economy has always been a significant source of employment opportunities, food and nutritional safety, foreign income, and aquatic biodiversity conservation (Ghose, 2014). Fish contributes about 60% of our daily animal protein requirements (Kashem et al., 2017).

The socio-economic impact of the fisheries sector is also remarkable. The Department of Fisheries (DoF), Bangladesh, has been playing a vital role in socio-economic development, contributing 3.57% of the national GDP and 26.50% to the overall agricultural GDP of the country (BER, 2021). Over 17 million people depend on the fisheries sector for their livelihoods through fishing, fish farming, fish handling, and processing (BFTI, 2016). Bangladesh has become one of the foremost fish-producing countries, with a total yield of 43.8 lac MT in FY 2018-19 (DoF, 2020). The fisheries can roughly be divided into three categories: inland capture fisheries, inland aquaculture, and marine fisheries, of which the inland aquaculture sector is contributing more than 55% of the total production (DoF, 2016).

Spoilage of fish is a significant issue in post-harvest management after catching fish. After catching, the spoilage process caused rapid perishability, known as rigor mortis, begins within 12 hours of their capture in the high ambient temperatures as the optimum temperature for microbial growth ranges from only 7 °C to 55 °C (Berkel et al., 2004). Rigor mortis is a phenomenon in which fish lose their flexibility after a few hours of death due to the stiffening of fish muscle (Adebowale et al., 2008). Different biochemical components face breakdown to create new components (Gokoglu and Yerlikaya, 2015), which account for the fish deterioration in odor, taste, and texture (Ghaly, 2010). In the broad sense, fish spoilage results from improper management and processing. Negligence in post-harvest management trims down the quality of the products. Quality deterioration is a significant concern to food security and public health (Béné et al., 2015). It also consequences tremendous economic loss for the fish traders. Therefore, it is domineering to formulate policy recommendations for taking adequate interventions for loss reduction. Policy recommendations and strategy preparation can be made by measuring post-harvest loss in different handling, distribution, and processing stages and developing suitable loss reduction interventions (Kruijssen et al., 2020).

The post-harvest loss in Bangladesh is also severe, and it is assumed that about 20-30% in different fish and fishery foodstuffs (Nowsad, 2007), and about 50% wasting in the post-harvest process could save up to Tk 80-100 billion per year (Nowsad, 2010). As fish get spoiled very rapidly, proper handling, processing, and distribution in time are necessary to maintain the quality (Ababouch, 2006). Fish foodstuffs have been attained for centuries from fresh fish through various processes, including cooling, heating, drying, salt treatment, etc. To preserve the quality of fish, two basic methods have primarily been practiced, namely chilled and frozen storage (Medina et al., 2009). In Bangladesh, ice is widely used for fish preservation for different post-harvest operations (Haider et al., 2020). Ice flakes with good quality can lessen the post-harvest loss of fish for sustainable fish management and processing scheme to improve the class of fish for consumers and increase incomes for fishers and traders (Devi and Raj, 2017).

Ice is generally produced as ice blocks, then crushed into small ice flakes (Shawyer and Pizzali, 2020). Several methods are used for ice-crushing. In the traditional process, particularly in small fish markets in Bangladesh, ice is crushed with a heavy wooden or bamboo stick, which is very laborious, time-consuming, and often does not deliver the uniform shape of ice flakes (Zhuang et al., 2020). Apart from that, a large quantity of ice is lost during the crushing process due to melting and scattering. Also, there is a probability of getting contaminated as most of the processing units are unhygienic. Few locally manufactured motor or engine-driven ice crushers can be found primarily on large fish markets but they are usually located far from where fish is caught, resulting in spoilage and increased post-harvest loss (Nidoni et al., 2013). Furthermore, these machines need electricity, which is scarce in remote fishing and processing zone in Bangladesh. Fishermen often have to crush ice on the catching site, which rarely results in good quality ice flakes with minimal loss. So, there must have a great apprehension to improve the quality of fish by reducing the post-harvest loss ensuring quality ice flakes, exclusively for the remote areas. Therefore, the study focused on developing a low-cost ice crusher machine for raw fish storage, which could aid food security and public health. This research study had a particular goal to develop and evaluate a hand-operated ice crusher to reduce the post-harvest loss of fish, providing good quality ice flakes for storing raw fish at the remote fish storage and processing units in Bangladesh.

## 2 Materials and Methods

### 2.1 Design and fabrication

A three-dimensional virtual model of the hand-operated ice crusher was designed using Fusion 360TM 3D design software (Company: Autodesk Inc.; origin: San Rafael, California, USA). The machine was constructed according to the three-dimensional design maintaining all the considerations. The machine was designed and fabricated at the workshop in the Department of Farm Power and Machinery, Bangladesh Agricultural University. Fig. 1 represents the perspective views of the designed machine.

Design parameters like weight, thickness, and width of an ice block, machine height, teeth design, arrangement, and RPM (revolution per minute) of the crushing cylinder were considered. The width of the feeding tray was 454.6 mm, which was designed considering the dimension of locally available ice blocks (482.6 mm × 292 mm × 82.6 mm), where the tray width was kept greater than the ice block width (292 mm). The optimum engine/motor power required for crushing ice block was 43W (Rifat, 2020). The clearance between the crushing cylinder and the feeding tray was arranged to adjust the thickness of the ice blocks in local markets. The design of the machine was kept simple in construction so that the machine

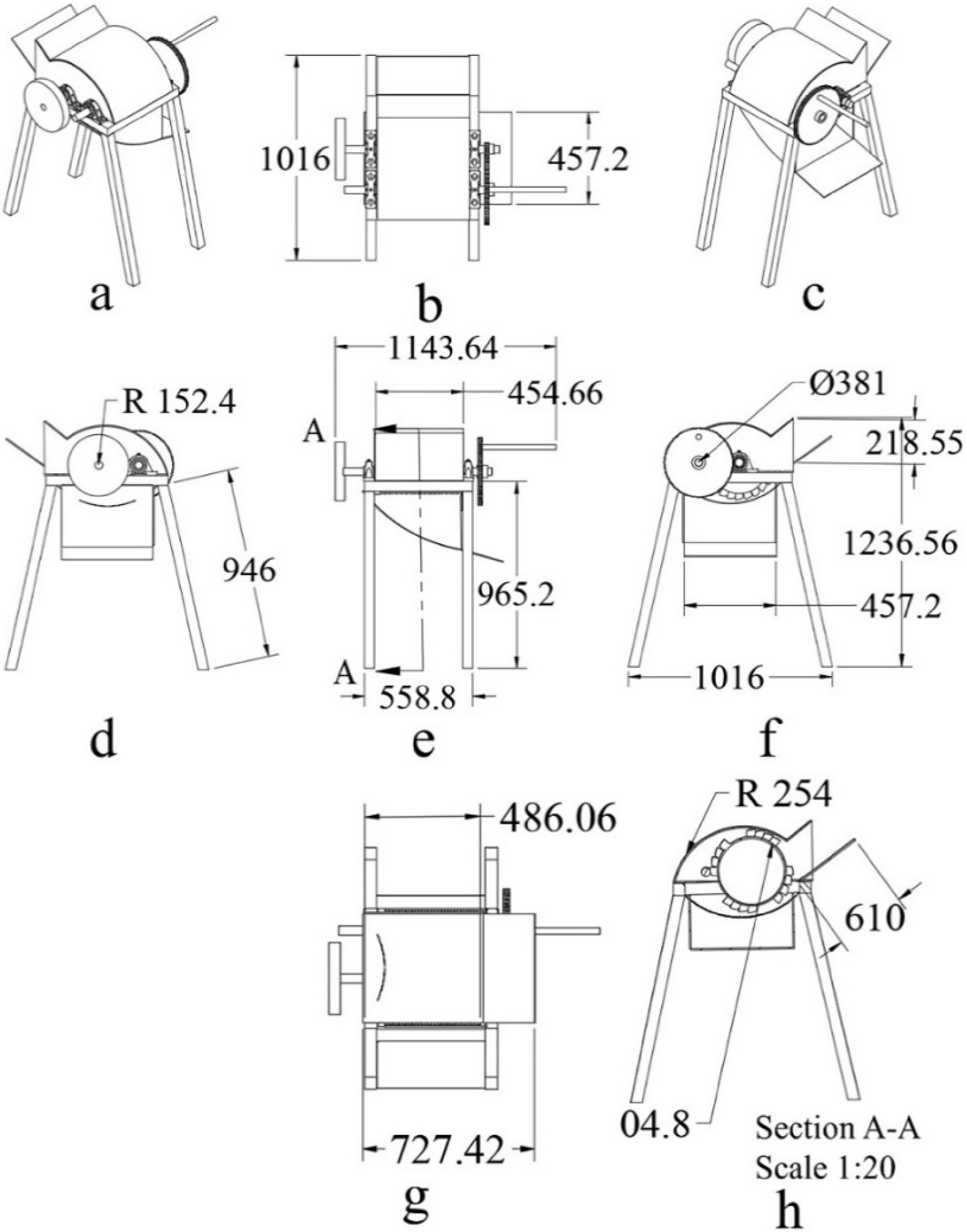


**Figure 1.** Perspective views of the designed machine: (a) top left, (b) top, (c) top right, (d) left, (e) front, (f) right, (g) bottom, and (h) section view (all measurements are in mm)

**Table 1.** Materials used for the construction of the crushing unit

| Material | Dimension | Quantity |
|---|---|---|
| MS plate | 304.8 mm diameter and 5 mm thickness | 2 |
| MS shaft | 38.1 mm diameter and 660.4 mm length | 1 |
| MS bar spike | (38.1 mm × 31.8 mm × 4 mm) | 30 |
| Metal sheet (cylinder) | 5 mm thickness | – |

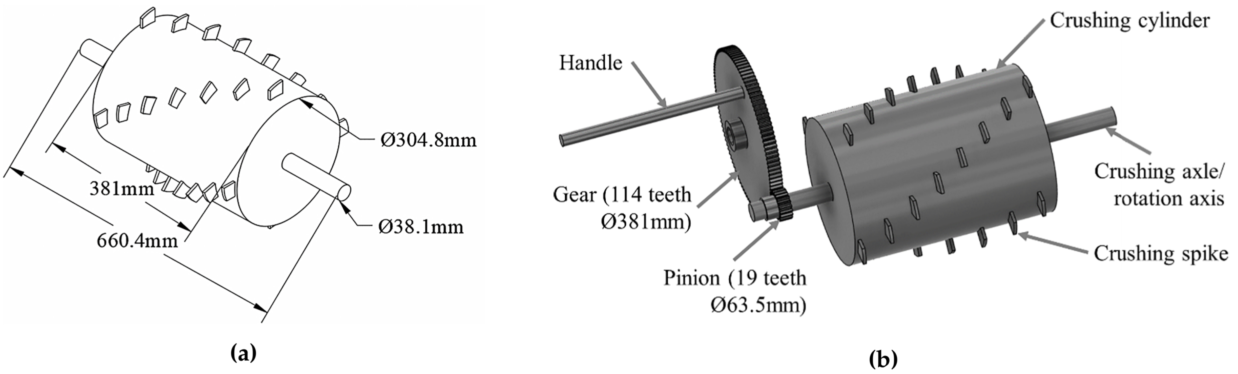


**Figure 2.** (a) Design of the crushing cylinder (b) Design of the power transmission unit

could be manufactured in local workshops. The entire machine consists of the following five major components, as described in the following sections:

**Feeding unit** It is a long-inclined tray that provides ice blocks to the machine for crushing. Its function is to carry the ice block to the crushing chamber, and the inclined inert flat plate assists to slide the ice block downward. This unit was made of 2.0 mm thick and 610 mm long MS sheet formed in a rectangular shape with an opening (454.7 mm × 218.6 mm) inclined at 60° with the horizontal surface to allow the ice block sliding due to body weight.

**Crushing unit** It is mainly a cylinder with spikes that function to crush the ice block. The materials used for making the crushing unit are listed in Table 1. The cylinder was made with bending MS sheet, and thirty individual spikes were welded on the cylinder surface. On the cylinder, MS bar spikes were spirally welded in four rows. Each row contains seven and eight spikes alternately. An equal distance of 239.4 mm was maintained between two consecutive rows. Fig. 2(a) represents the design of the crushing cylinder. A metal shaft (38.1 mm) was inserted throughout the cylinder, which served as the rotation axis and also supported the cylinder to be in position (Fig. 2(b)).

**Outlet** The outlet unit was supported by a simple arrangement that enabled crushed ice to flow out directly from the crushing unit to the pan or other collecting unit beneath it. The outlet of the machine was consisted of a 3.0 cm wire net sieve to let the small crushed ice flakes fall on the bucket from the crushing unit. An inclined tray was provided for easy sliding of the crushed ice. The length and width of the outlet tray were 727.4 × 457.2 mm, respectively.

**Power transmission unit** A basic gear pinion mechanism was mounted on the left-hand side of the machine. The gear has 114 teeth with a tip diameter of 381 mm. The pinion has 19 teeth with a tip diameter of 63.5 mm. The gear and the pinion are directly engaged to each other. The pinion is directly connected with the shaft of the crushing cylinder. A handle was attached near the outer corner of the large gear to rotate the cylinder. The cylinder RPM increases as per the gear-pinion teeth ratio (6:1). A counterweight was attached with the pinion shaft (crushing axle) opposite the power transmission system to increase its momentum. The design of the power transmission unit and the design of the crushing cylinder are shown in Fig. 2.

**Frame and cover** The frame served as the foundation for the rest of the parts. The size of the frame was 965.2 mm × 558.8 mm × 457.2 mm by length, width, and height. The frame was constructed with a 3.0 mm MS angle bar. The cover was provided to prevent the throwing of the crushed ice to the upper portion of the crushing unit and so the crushed ice can be collected from one side. It was also bent at a round shape to maintain uniform spacing from the crushing unit. The cover was curved with a 254 mm radius. The feeding tray was attached to this covering unit. The maximum clearance of 100 mm was kept between the crushing cylinder at the end of the opening for ice block for smooth passing. Then the clearance was tapered to only 25 mm at the bottom of the cylinder to make the ice flakes smaller with every impact and get the desired size.

The pictorial view of the developed machine is shown in Fig. 3. The entire machine had a length of 1016 mm, a width of 1143.6 mm, and a height of 1236.6 mm. The machine requires an operator and a laborer to operate. The machine weighed 76 kg in total. The structure of the machine is also kept lighter. It is easily portable in village roads by a rural van.


**Figure 3.** Photograph of the developed machine

## 2.2 Performance evaluation

The overall machine performance was evaluated in terms of mechanical properties, crushing cylinder RPM, vibration, and noise level.

### 2.2.1 Mechanical properties

The mechanical properties of the crushing unit were evaluated based on total deformation of the spike, shear stress, strain energy, maximum shear stress, shear elastic strain, and structural error that occurred on a single biting spike of the crushing cylinder while crushing ice. The error properties were obtained at maximum pressure imposed on the contact surface of the spike and the ice block. The compressive strength of an ice block was reported within the pressure range of 5–25 MPa and the temperature range of −10 °C to −20 °C (Petrovic, 2003). Kim and Keune (2007) reported a high strain range for crushing ice blocks as 10-30 MPa. In this study, the maximum compressive strength was considered for evaluation.

A Finite Element Analysis (FEA) was performed to estimate the deformation and error properties using ANSYS Workbench 2020 R1 simulation software (ANSYS, Inc., Canonsburg, Pennsylvania, USA). FEA using ANSYS is a simulation procedure that significantly relates to numerical solutions and can be a perfect alternative (Abdelrhman et al., 2016), so ANSYS was used to predict mechanical errors for understanding the mechanical fitness of the developed machine. The 3D design of a single spike of the crushing cylinder was created with Fusion 360 CAD software. Tetrahedral method of mash with an element size of 0.003 m (element nos.: 15869, nos. of nodes: 29880) was applied to mash the design. After mashing, the model was subjected to assign material properties and forces acting on different surfaces. A pressure of 30 MPa was imposed on the biting surface of the spike, considering the highest possible pressure that can be imposed on it, and the other parts were considered to be fixed support for the spike. The material used for the whole structure was mild steel (Young Modulus: $2 \times 10^{11}$ Pa, Poisson Ratio: 0.3, Bulk Modulus: $1.7 \times 10^{11}$ Pa, and Shear Modulus: $7.7 \times 10^{10}$ Pa). The analysis was conducted using the method described by Lee (2018) and Hutton (2004).

### 2.2.2 Crushing cylinder RPM

The RPM of the crushing cylinder was measured using an RS PRO tachometer (Manufacturer: RS Components, Headquarter Corby, United Kingdom). The contact method was used for measuring the crushing cylinder RPM. The RPM of the cylinder was measured with one second interval throughout each trial.

### 2.2.3 Vibration

The rotation of the crushing cylinder and the crushing operation result in the vibration of the machine. Vibration rises to peak while crushing the ice block, especially at the first hitting of the ice block. The smartphone application 'iDynamics' (Developer: Department of Civil Engineering, Technical University of Kaiserslautern, Germany, 2017) was used for vibration measurements. The smartphone used for the test was the Xiaomi Redmi Note 10. The phone has a higher resolution (>1 mm $s^{-2}$), and the software can detect amplitudes as low as 100 mm $s^{-2}$. At 250 mm $s^{-2}$, there is less than a 20% amplitude defect. The percent error is reduced with a much higher amplitude with a low-frequency rate (Feldbusch et al., 2017). The mobile phone was firmly attached to the most distant part of the machine body near the handle where the vibration is high and affects the operator most. The app has recorded vibration amplitudes, natural frequencies, velocity, and displacement at an interval of one millisecond. The app detects vibration parameters in a three-dimensional perspective using the in-built accelerometer and gyroscope of the mobile phone. The axis with respect to the phone orientation is shown in Fig. 4.

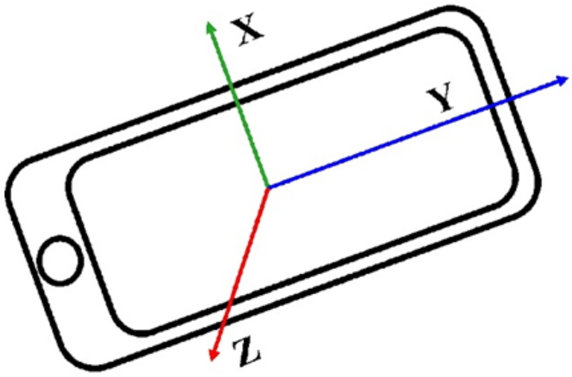


**Figure 4.** Axis direction of vibration measured by iDynamics

#### 2.2.4 Noise

As the crusher machine produced a massive noise while crushing the ice blocks, it was important to verify whether the noise level was hazardous to the operator. According to Sims and O'Neill (1994), the suitable range of noise for the operator is 80 dB when the operator is constantly working over 8-hours in a working day. The noise level was measured at a one-second interval for three different stages, e.g., before crushing, during crushing, and after crushing. The noise level was measured in the dB unit using Extech 407736 dual range type two sound level meter (Developer: Extech Instruments company, Headquarter: New Hampshire, United States).

### 2.3 Technical parameters for performance evaluation

For testing, the machine was fixed to a flat concrete floor to be well balanced and eliminate excessive vibration. A plastic basket was placed at the outlet of the ice crusher. A single ice block weight was determined using the weight balance and fed through the feeding unit. Crushing time was measured using the stopwatch. The crushed ice flakes weight was taken again by the weight balance immediately after the crushing. The size of the ice flakes was measured by the sieve analysis method, and a small portion from the whole crushed ice was taken randomly as a sample to measure with the slide calipers for deriving the range of size of the ice flakes more precisely. This process was done as quickly as possible to avoid the ice melting. The technical parameters (machine throughput, fineness of ice flakes, loss measurement, ergonomic appraisal) were considered for performance testing of the ice crusher.

#### 2.3.1 Machine throughput

Throughput is a way to measure the effectiveness of a machine. In technical terms, it is the production rate, i.e., how much a machine can produce/deliver over a certain period. For a machine, throughput is highly related to efficiency, equivalent to uptime percentage. Machine throughput was derived by dividing the weight of crushed ice by the time required to crush the whole ice block. It was calculated using the following mathematical formula:

$$MT = \frac{W}{t} \tag{1}$$

where $MT$ = machine throughput (kg min$^{-1}$), $W$ = weight of crushed ice (kg), and $t$ = time of crushing (min).

#### 2.3.2 Fineness of ice flakes

The fineness of the ice flakes is a qualitative parameter which was measured in terms of the size of the ice flakes. The percentage of different fineness categories indicated the qualitative performance of the machine. The more the percentage of small-sized ice flakes, the quality is better.

#### 2.3.3 Percent weight loss

Some portion of the ice block melted while crushing operation, which was considered as a loss. It was calculated using the following mathematical formula:

$$WL = \frac{W_b - W_c}{W_b} \times 100 \tag{2}$$

where, $WL$ = weight loss (%), $W_b$ = weight of ice block (kg), and $W_c$ = weight of crushed ice (kg).

#### 2.3.4 Ergonomic appraisal

This section provides the fundamental approach to whether the machine is user-friendly and provides optimum performance while ensuring labor safety and comfortable use (Pheasant, 1991). The ergonomic testing was conducted from a direct human health aspect and the effect of the machine on the surrounding environment. The operators' weight, strength, and height must be compatible with the machine. Five healthy and professional laborers (machine operators) were selected as a subject for the study. The general information of each subject was taken regarding their health condition is listed in Table 2.

An operator and assistance are required for operation, and assistance is needed to assist the operator in feeding the ice block into the machine. Since the operator's contribution pretends to encounter some ergonomic issues, some ergonomic metrics, e.g., blood pressure, pulse, and respiration rate were recorded before and after the operation to assess workload

**Table 2.** General information of the subjects

| Parameters | Operator 1 | Operator 2 | Operator 3 | Operator 4 | Operator 5 |
|---|---|---|---|---|---|
| Age | 29 | 28 | 32 | 28 | 37 |
| Height (m) | 1.6 | 1.7 | 1.6 | 1.6 | 1.7 |
| Weight (kg) | 67.5 | 67.8 | 73.2 | 70 | 75.8 |
| BMI | 24.9 | 23.5 | 26.2 | 24.8 | 25.3 |

BMI: body-mass index (weight/height$^2$)

impact on the labor health. An automatic blood pressure monitor (ReliOn BP100, Model: BP3UP1-1ARL, Manufacturer: OBL: Walmart Apollo LLC (ReliOn), City: Bentonville, Arkansas, Country: United States) was used for the measurement of blood pressure and pulse rate. The respiration rate was manually measured before and after each operation by counting how many times the chest (diaphragm) rose during one minute of breathing (Elliott, 2016).

# 3 Results and Discussion

## 3.1 Analysis of mechanical properties

Fig. 5 demonstrates the result of finite element analysis conducted to critically evaluate the crushing impact on the unit, especially on an individual spike. The finite element analysis results show that with a maximum load of 30 MPa imposed on the crushing surface of the spike, it will encounter a maximum total deformation of 0.0046 mm in one impact (Fig. 5a). This amount is negligible in support of the elastic property of the structure material. The maximum deformation happens at the biting face of the spike. Karaveer et al. (2013) carried out a similar study for the spur gear teeth, and they stated that the deformation in one tooth was negligible (0.206 mm) for a single impact. The analysis results show that the strain energy imposed on the crusher spike due to crushing impact is 0.0031 MJ (Fig. 5b), where the maximum shear stress is noted at the contact point of the spike and the cylinder with a value of 28 MPa (Fig. 5c). The maximum share stress is much lower than the allowable stress of structural steel (140-360 Mpa) (Inose et al., 2003). A structural error is also encountered at the upper contact point of the cylinder and spike, which is 0.0025 MJ (Fig. 5d).

Table 3 shows RPM values of the crushing cylinder for five trials. The maximum RPM before the operation was found 656, where the average was 426. While crushing operation, the maximum RPM of the crushing cylinder was recorded at 635, where the minimum and average RPM were 358 and 494, respectively. The maximum RPM of the crushing cylinder after crushing was 416, and 286 was the average RPM.

For easy interpretation, the whole crushing time has been divided into three parts: before crushing, during crushing, and after crushing, as shown in Fig. 6. As there was no load on the cylinder before crushing, the speed of the crushing cylinder increased exponentially. After reaching the maximum speed, an ice block was inserted. Immediately after the first hit, the RPM started to reduce because of restraining from the ice block. The reduction of RPM continued throughout the whole crushing time. Immediately after the crushing was over, the cylinder RPM increased exponentially as before crushing. After leaving the handle, the cylinder continued to rotate with its momentum, and the RPM decreased gradually till the cylinder came to a stop. Table 4 shows the data of different trials as mentioned.

The data set for acceleration collected from the app was later analyzed to discuss the nature of the vibration during the whole operation time, as shown in Fig. 7. It illustrates the behavior of the machine vibration over time as the machine accelerated. Fig. 8 shows the distribution of vibration frequency to all three dimensions. After the first hit on the ice block, the cylinder faces a tremendous bump, resulting in the mitigation of the crushing cylinder RPM. As a result, the machine vibration starts to fall again. But immediately after the crushing is over at 36th second; the machine is again induced with high vibration due to further increase in RPM. When the operator releases the handle, the machine vibration gradually decreases with the cylinder RPM.

The maximum vibration occurs at 9-15 Hz. The vibration in X-axis is lower than the other two axes, and the maximum vibration occurs in the Y direction. The reason for this is the force exerted on the Y-axis while rotating the large gear. The maximum vibration and acceleration were lower than the allowable range in hand-arm equipment usage. The acceleration and vibration frequency for occupational exposure to hand-arm vibrations range up to 5 m s$^{-2}$ and 8-80 Hz, respectively (Druga et al., 2007). Fig. 9 depicts the machine noise level, which fluctuates during operation. Most of the time, the noise produced during the whole process is within the permissible range. Fig. 10 portrays the average noise level before crushing, during crushing, and after crushing. Fig. 10 also reveals that the noise level during crushing is significantly higher ($p<0.01$), whereas there is no noticeable difference between before and after crushing.

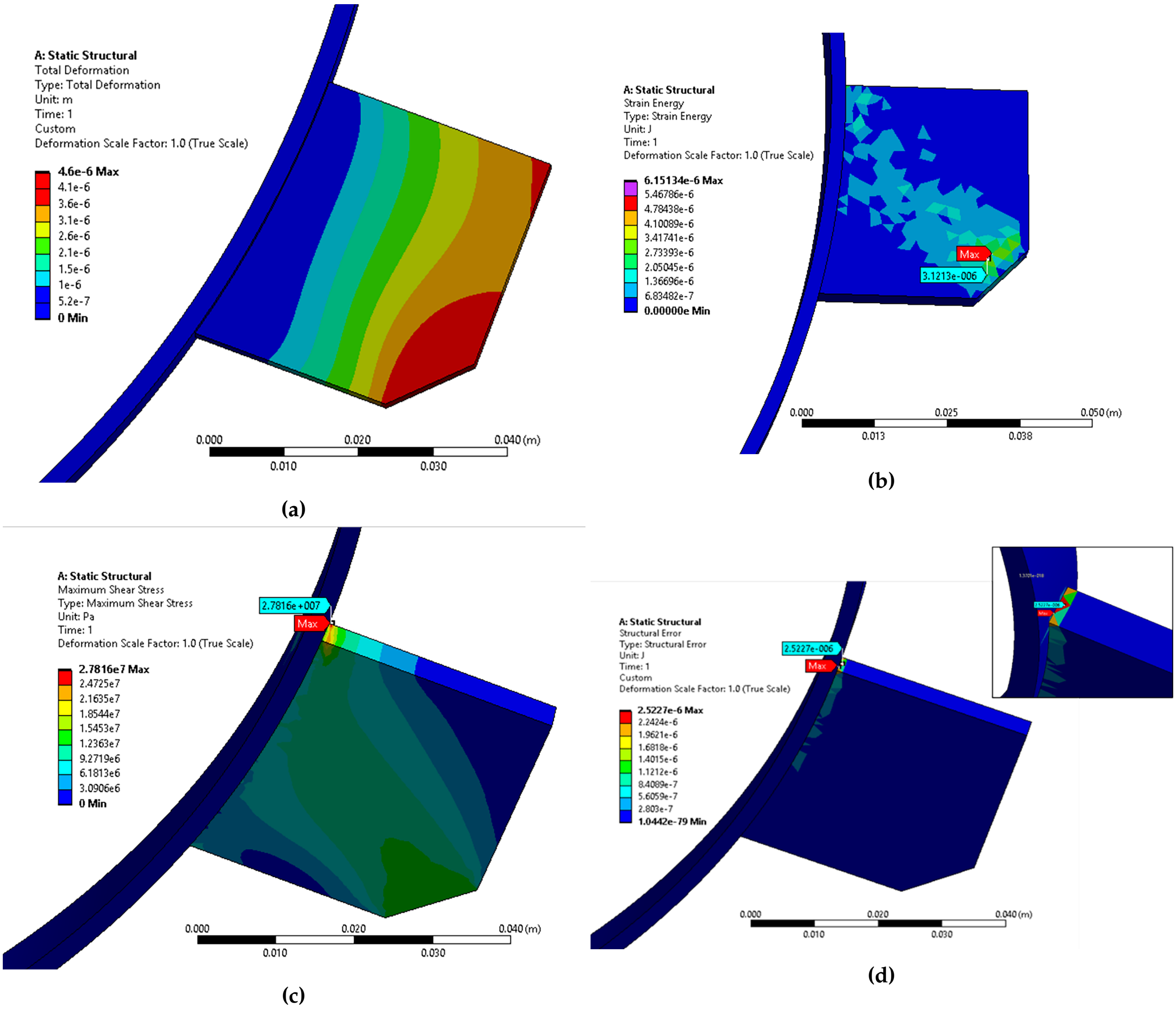


**Figure 5.** Mechanical properties of the crushing unit: (a) Total deformation (b) Strain energy (c) Maximum share stress (d) Structural error

**Table 3.** The RPM of the crushing cylinder for different trials

| | | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Average |
|---|---|---|---|---|---|---|---|
| Before crushing | Max | 672.7 | 705.5 | 553.3 | 724.9 | 624.1 | 656.1 |
| | Avg | 531.2 | 454.6 | 360.6 | 426.4 | 354.6 | 425.5 |
| During crushing | Max | 617.5 | 683.7 | 540.3 | 713.1 | 618.8 | 634.7 |
| | Min | 317.8 | 388.1 | 292.2 | 355.4 | 436.1 | 357.9 |
| | Avg | 531.2 | 503.8 | 364.4 | 549.7 | 519.1 | 493.6 |
| After crushing | Max | 380.1 | 390 | 358.9 | 528.6 | 423 | 416.1 |
| | Avg | 194.5 | 278.3 | 304 | 384.8 | 266.3 | 285.6 |

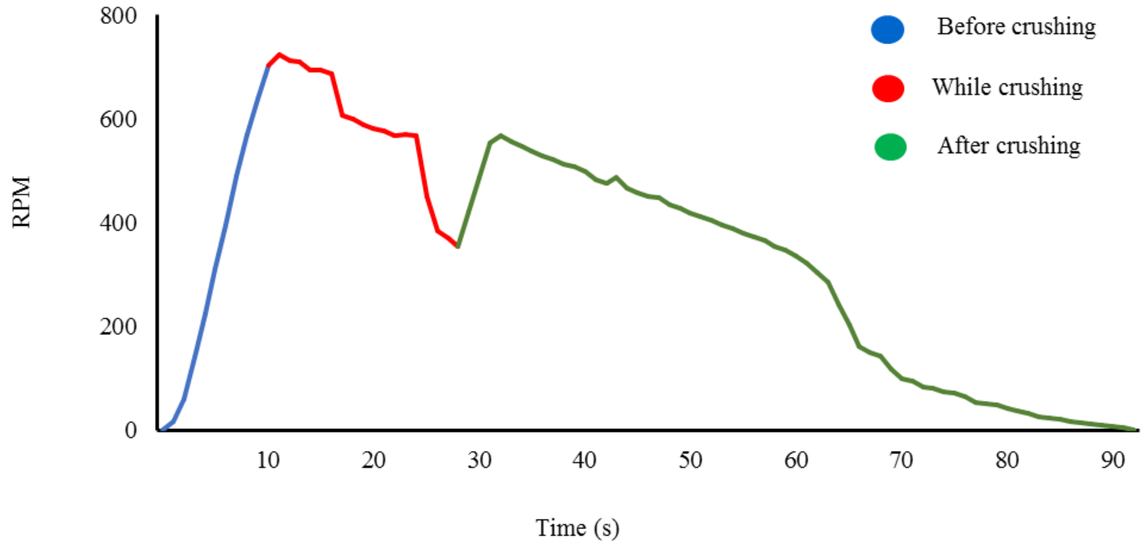


**Figure 6.** Characteristic of RPM during operation of one trial

**Table 4.** Vibration characteristic of the machine

| Axis | Average± SD | | |
|---|---|---|---|
| | X | Y | Z |
| Average frequency (Hz) | 8.5±0.4 | 8.5±0.3 | 8.4±0.4 |
| Max. acceleration (m $s^{-2}$) | 4.8±0.6 | 7±0.9 | 10.6±1.7 |
| Max. velocity (m $s^{-2}$) | 0.1±0.04 | 0.1±0.01 | 0.2±0.04 |
| Max. displacement(m $s^{-2}$) | 0.03±0.01 | 0.03±0.03 | 0.07±0.02 |
| Acceleration RMS (m $s^{-2}$) | 0.7±0.1 | 0.7±0.2 | 1.4±0.3 |

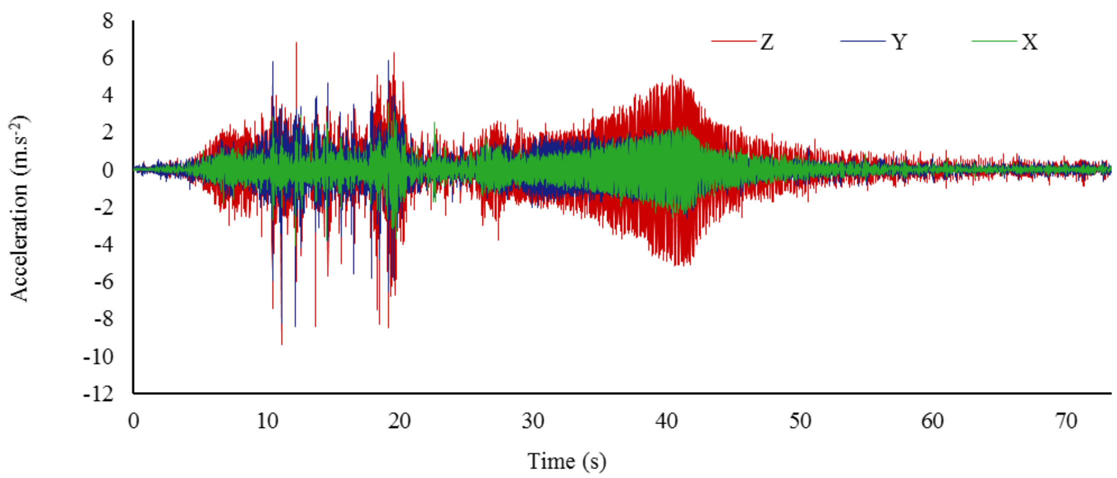


**Figure 7.** The vibration of the machine in three axes during operation

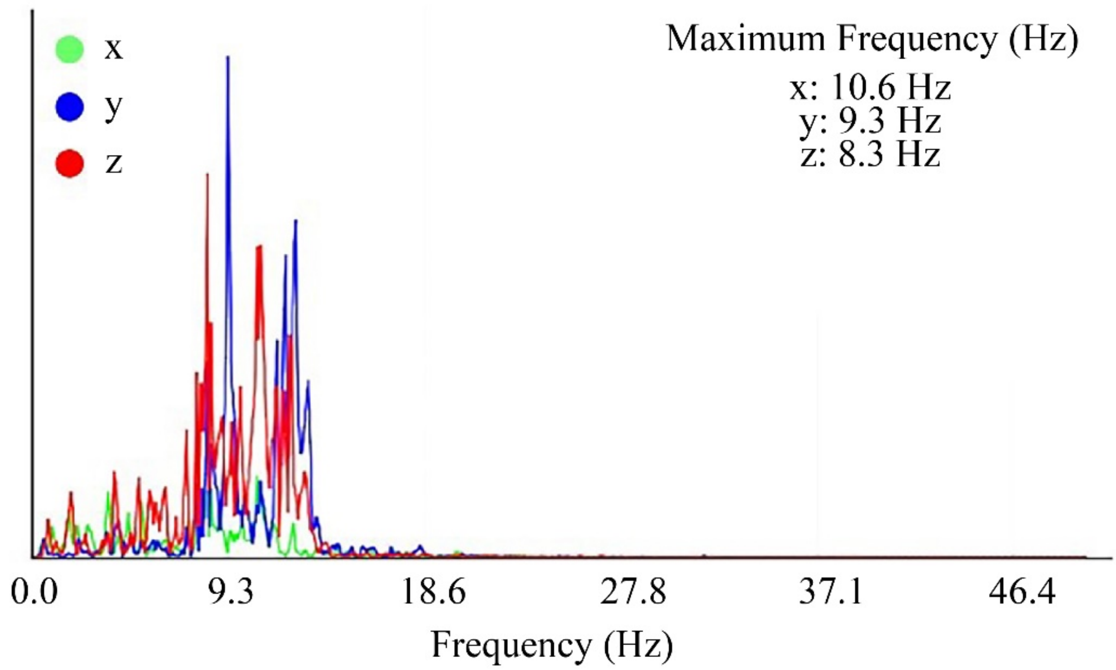


**Figure 8.** Histogram of frequency in different axis

The noise level was normal before the operation (<60 dB). However, the noise level increased gradually with the increase of cylinder RPM. Until the crushing began, the noise was at the normal level, but the noise surpassed the normal level just after the crushing began. During crushing time, the maximum noise level rose to 92.9 dB (Fig. 10) for all five trials, but the mean noise level was 78.1 dB within normal noise levels. It indicates that the noise level produced by the machine is within the comfortable range for the operator. According to OSHA (2006), Noise Exposure Computation, for an eight-hour time-weighted average (TWA), the permissible exposure limit (PEL) for noise is 90 dB. Except for the crushing time, the noise level before and after crushing the ice block was within the acceptable range for maximum and mean noise levels.

## 3.2 Technical parameters

Table 5 shows the testing parameters that came out after estimating the technical parameters for performance evaluation. From Table 5, it was found that the average crushing time of a single ice block was 21.6 seconds, and the machine throughput was 21.64 kg $min^{-1}$. The size of the crushed ice was classified into three groups. The small-sized ice was on an average of 76.3%, the medium-sized ice was on an average of 12.9%, and the rest were large-sized. The results also show that the small size is significantly higher ($p<0.01$) than the medium and large size of crushed ice, and there is no such significance in comparison between medium and large size. According to Shawyer and Pizzali (2020), the optimum size of the ice flake remains less than 3 cm. So, the machine was found efficient in crushing ice to an optimum size.

## 3.3 Ergonomic performance

The machine being hand-operated, an operator could not operate the machine continuously. Fig. 11 shows the maximum operating time and number of crushed ice blocks with respect to the operator's BMI. Results show that the operators can operate the machine for 16 minutes, and the average number of crushed ice blocks is 22. From Fig. 11, the number of crushed ice blocks and the continuous operating time varies with the BMI of an operator. The BMI of less than 26 resulted in good efficiency in crushing ice with the developed machine.

Table 6 shows the average impact of machine operation on human health, e.g., blood pressure, pulse rate, and respiration rate after a continuous operation of 15 minutes. Adults' average respiratory rates are 12-20 breaths per minute (Yuan et al. 2013), and if the respiration rate falls below 12 or rises above 25 breaths per minute, it is considered abnormal (Cleveland Clinic, 2019). The average systolic pressure was 118.4 mm (Hg) to 141.8 mm (Hg), and the diastolic pressure was 72.9 mm (Hg) to 84.5 mm (Hg), according to a study of men ranging in age from 16 to 64 (Master, 1950). However, systolic blood pressure may increase from 160 mm (Hg) to 220 mm (Hg) after an intense workload or exercise (Vandergriendt, 2018).

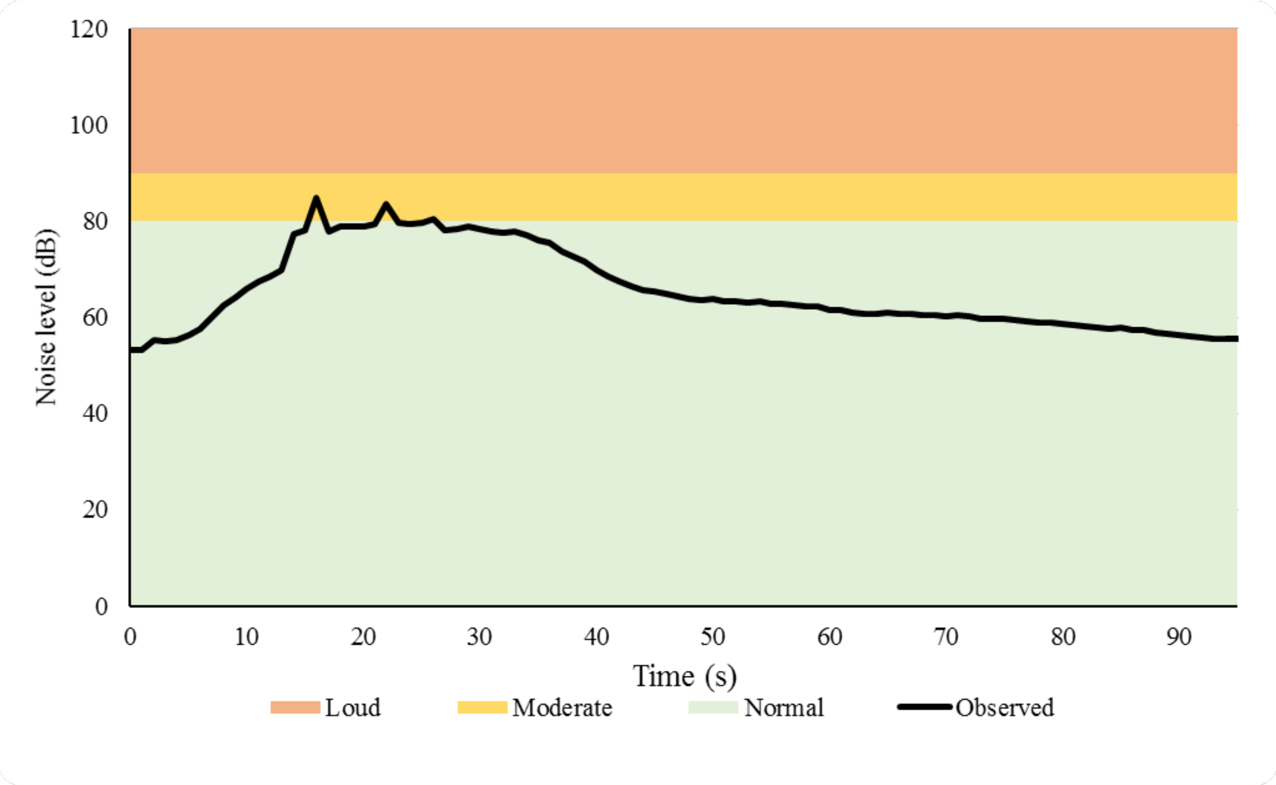


**Figure 9.** The noise level of the machine during the operation

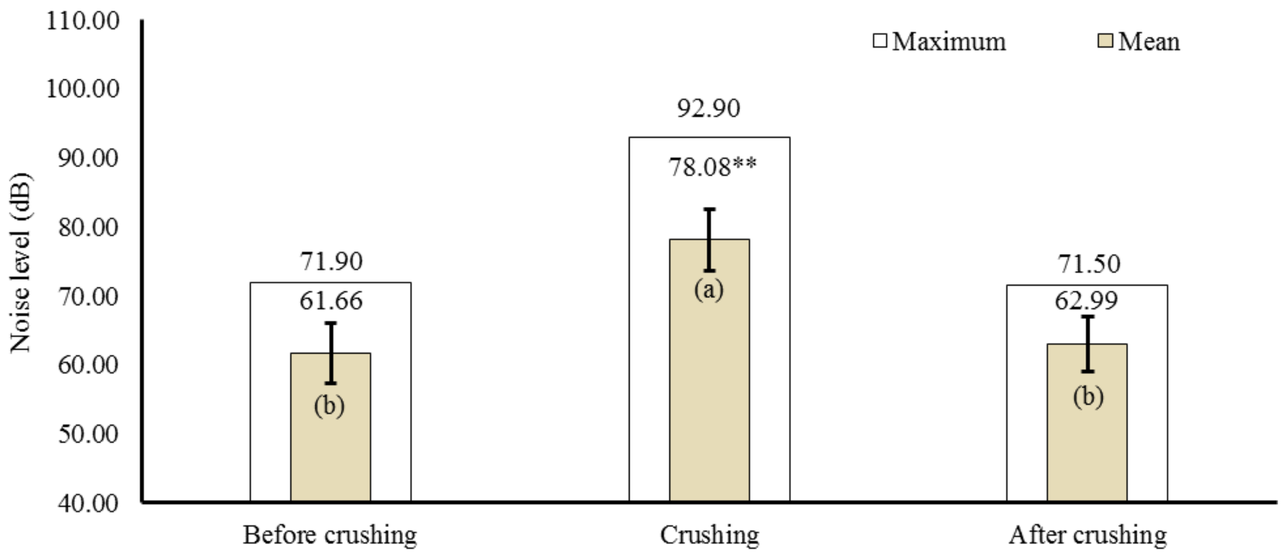


**Figure 10.** Maximum and mean noise level of the machine (**significant at p<0.01)

**Table 5.** Performance test parameters of modified ice crusher

| Parameters | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Average ± SD |
|---|---|---|---|---|---|---|
| Wt. of ice block (kg) | 10.8 | 10.5 | 10.4 | 10.6 | 10.7 | 10.6±0.1 |
| Wt. of crushed ice (kg) | 9.2 | 9.1 | 9.1 | 9.3 | 9.4 | 9.2±0.1 |
| Wt. loss (%) | 14.2 | 13.9 | 12.9 | 12.5 | 12.1 | 13.1±0.9 |
| Time of crushing (s) | 21 | 23 | 23 | 17 | 24 | 21.6±2.8 |
| Machine throughput (kg $min^{-1}$) | 1842.9 | 1646.6 | 1632.5 | 2244.7 | 1600.5 | 21.6±3.3 |
| Percentage of crushed ice | | | | | | |
| Small (<1.5 cm) | 73.6 | 77.3 | 73.4 | 82.2 | 75 | 76.3±3.6a* |
| Medium (1.5-3.0 cm) | 16.2 | 13.3 | 11.4 | 8.1 | 15.5 | 12.9±3.3b |
| Large (>3.0 cm) | 10.2 | 9.4 | 15.2 | 9.7 | 9.5 | 10.8±2.5b |

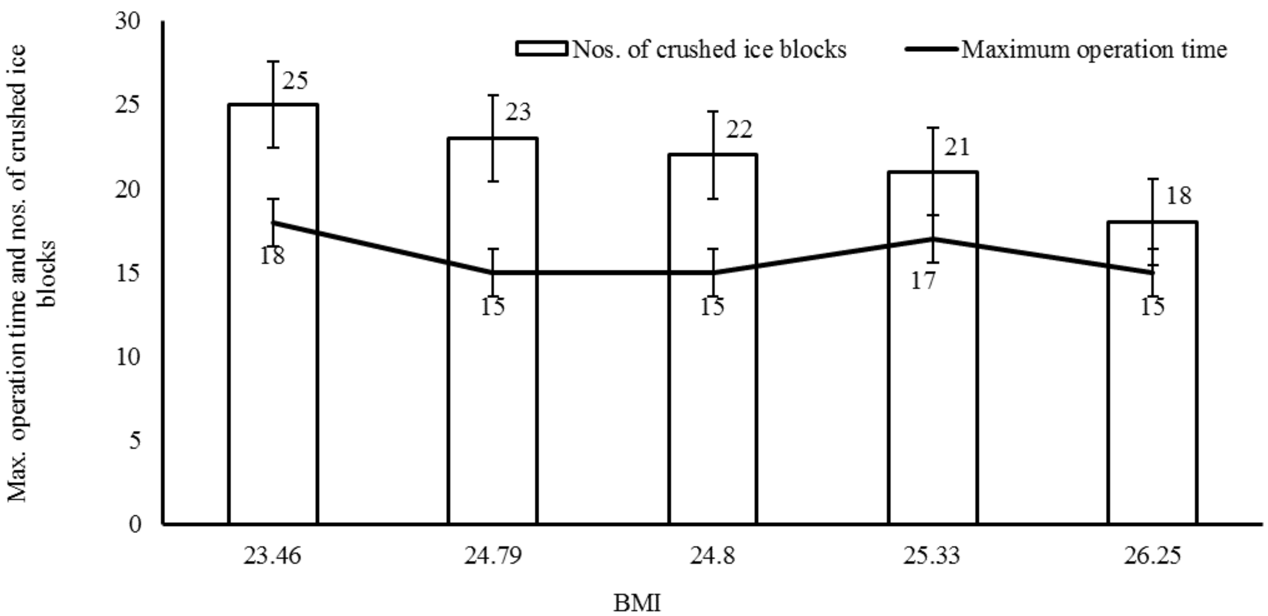


**Figure 11.** Maximum operating time (min.) and nos. of crushed ice blocks vs. BMI of operator

**Table 6.** Ergonomic parameters before and after the operation

| Parameters | Before operation | After operation | Difference |
|---|---|---|---|
| Blood pressure, mm (Hg) | | | |
| Systolic | 120.6±2.3 | 138.4±4.1 | 17.8±6** |
| Diastolic | 65.6±2.5 | 74.2±5.5 | 8.6±3.6** |
| Pulse rate per minute | 74.2±16.6 | 105.4±14.6 | 31.2±10** |
| Respiration rate per minute | 15±2.2 | 20±1.6 | 5±1.3** |

Double asterisk (**) designates significant at p<0.01 (two-tailed t-test)

According to the data obtained, blood pressure, heart rate, and respiration rate are all within the acceptable range after the procedure. So, the machine can be said ergonomically safe for the operator.

## 4 Conclusion

To mitigate the post-harvest loss in fish processing, a hand-operated ice crusher was developed for rural fish farmers of Bangladesh, and the system performed admirably in crushing ice in terms of precision and ergonomics. Mechanical properties of the crusher were found to be adequate for crushing ice with limited deformation and structural error. The total throughput of 21.6 kg $min^{-1}$ achieved the expectations satisfactorily. Since crushing, there was a 13.1 percent net loss of ice, and the yield of ice flakes was of high consistency, with small-sized ice accounting for 76.3 percent, medium-sized ice for 12.9 percent, and the rest were large-sized. After operating the machine, the health of the operator was evaluated, and the parameters were found within the acceptable range. The developed ice crusher machine provides the benefit of convenient portability and pretends itself as a perfect and superior alternative to traditional crushing for on-spot fish preservation, reducing the fuel and electricity expenses, ensuring timeliness, uniformity, and hygiene. The machine has an anomaly of interrupted operation as an operator cannot operate it continuously. Furthermore, the force applied to run the system could not be measured due to a lack of proper instrumentation. However, the built machine should be tested from the consumers' perspective, and further study on its effectiveness in large-scale operations should be conducted. Despite some drawbacks, the developed ice crushing machine is effective for immediate fish storage with ice in areas where the electricity supply is inadequate.

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## Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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