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Investigation of vibrating jaw crusher experimental variables

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Abstract

Purpose. Current research focuses on studying experimentally various parameters affecting the particle size produced in a vibrating jaw crusher developed and implemented at Al-Balqa Applied University. The main purpose is to find the optimal conditions at which the jaw crusher under study works.

Methods. The jaw crusher angle and rotating mass type are considered to study all particle sizes and reduction ratios obtained for three different motor operation speeds: 1500, 2000, and 2500 rpm. Coarse aggregate weighing 900 g with 26 mm particle size is fed into the jaw crusher, which produces several particle sizes (19, 12.5, 9.5, 4.75, and less than 4.75 mm). Furthermore, the mass of the particles is measured and the particle size reduction is calculated.

Findings. It has been found that the jaw crusher angle, rotating mass type, and the motor operation speed play an important role in both reducing the amount of mass and reducing the size of each particle produced. In addition, it has been determined that operation at a speed of 2000 rpm provides a significant change in both mass and size reduction of each particle size considered.

Originality. The originality of this research lies in its experimental investigation of the effects of various parameters on particle size reduction in a vibrating jaw crusher, as well as in the introduction of a new design that uses one motor to drive two plates operating at different speeds and in opposite directions.

Practical implications. The findings can be used to optimize the design and operation of jaw crushers in various industries, including metallurgical, quarry, and mining industries, where these crushers are widely used. The results of this study can also serve as a basis for future research on particle size reduction in other types of crushers and milling equipment.

Keywords: *jaw crusher, crushing, vibration, milling, material*

1. Introduction

Grain quality in addition to jaw crusher speed and feed rate were experimentally investigated to determine their impact on crusher functions. It has been found that the mechanical properties of the produced grains did not change significantly during the crushing operations [1]. At the same time, several experiments were conducted to study the effect of particles size and operation speed on the final product size. The results show that the increase in speed leads to an increase in crushing time, which in turn reduces the particle crushing speed [2]. However, the gold-bearing ore crushing process was simulated in order to verify the results with experimental data. It should be said that frequency effect was observed for the compression force during the crushing operation [3]. Performance of vertical shaft crushing machine was compared to cone one in terms of energy consumption and particles size reduction. It should be mentioned that the vertical crusher was found to be more efficient as it produced smaller particles at less power [4]. Multiple jaw crushers were compared in terms of energy consumption and particle size reduction.

Modeling of a single toggle jaw as a plane crank and rocker mechanism was performed in order to obtain the mathematical equation, which describes the mechanism [5]. Moreover, jaw crushers can be disassembled and transferred to other locations. It should be noted that the simple design, reliability, ease of maintenance, in addition to higher capacity, are also among the jaw crusher advantages.

Several parameters were investigated in a shock centrifugal disintegrator comparing single and two chamber performances, where the rotor speed was considered in addition to input material size and type [6]. Experimental work using the new vibrating mill design has been conducted to study the impact of several variables, including motor speed and initial material size [7]. It has been found that the rotating mass plays a significant role affecting the processing time. Moreover, the crushing of different rubble waste sizes using two-stage processing was considered in order to cope with the large amount of waste produced every year [8].

A vibrating jaw crusher, which is a machine for crushing natural stone with a certain size, is widely used in metallurgical, mining, building materials, chemicals and coal industries. The jaw crusher can be used to crush rocks ranging in hardness from medium to extremely, as well as various types of ores, building rubble and glass, as well as other hard materials. It should be said that various industries use vibrating jaw crushers, particularly mining and construction sectors [9].

Dynamics analysis has been carried out to describe the mechanism of double toggle jaw crusher [10]. The jaw crusher was modeled as a six-bar linkage to obtain a mathematical equa-

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tion representing the mechanical structure kinematics. It should be noted that the dynamic performance was studied for different structures containing various composite materials during the deformation and stress analysis [11]-[13]. A similar analysis was performed using seven bar mechanism [14]. A jaw crusher digital design was performed using the SolidWorks platform, while studying parameters for optimization purposes [15].

A numerical model has been developed to study the impact of the gap between the jaws in addition to velocity recovery factor on the synchronization of the exciters [16]. A pendulum motion electric motor was installed and investigated to develop a suitable algorithm for operating at resonance frequency [17]. The dynamics of the jaw crusher during crushing process of hard metals has been studied, since a sudden change of shear forces has been noticed [18]. It should be said that most cases, jaw vibrations are induced by either two or four rotating mass vibrators [19], [20]. However, as a rule, the operating range for jaw crushers is within $r = 0.6\text{-}0.8$ (where $r = \omega/\omega_n$ and ω_n is natural frequency of vibrations). Hence, an increase in the plate vibration induces an increase in the jaw vibration frequency, according to the plot of the first resonance frequency branch of induced vibrations of the system with a single degree of freedom [21].

Analysis of a jaw crusher failure, caused by structure fatigue, was carried out experimentally and numerically [22]. Results showed that the main cause of structure failure is fast-growing fatigue cracks formed during operation. A single jaw vibrator with constant angular velocity and unbalanced vibration was studied [23].

Vibration characteristics such as natural frequency have been experimentally investigated for a moving dismounted jaw crusher [24]. Single-particle impact tests were used to model the grinding of polymers, limestone, and glass spheres, where breakage probability methods were considered to describe the effect of material properties and initial particle size on impact grinding product [25]. It should be noted that vibration analyses have been carried out on composite surfaces to study the effect of dynamic load on different materials [26]-[28].

This paper presents a new design of a double moving jaw crusher a single driving motor. A gear box is installed to transfer the angular motor velocity to the plates using multiple shafts, but with opposite rotation directions. It should be said that the angle of the jaws is adjustable. However, each shaft has a rotating mass with eccentric distance to enhance the process and crushing productivity. The sizes of the produced particles and each particle size reduction in addition to the time of the crushing process are measured by varying the rotating mass, the angle of jaw and the speed of motor.

A double-acting structure is designed with the vibration exciter installed on the movable jaw. The exciter eccentric mass is set to be the same as the vibrator reverse rotation, and the horizontal component force is always balanced. Thus, the equipment does not require large foundation and anchor bolts for installation and use, which is convenient for industrial selection and application [17].

According to the utility model with the above technical solution, the double-action vibrating jaw crusher has a flexible structure, uses a vibration exciter to provide working power, and can efficiently crush high-hard materials. Thanks to special designs, it is easy to assemble without requiring a large foundation and pre-buried ground. Foot bolts can be widely used in crushing various brittle materials [15].

2. Materials and methods

The material used in the crushing process is coarse aggregate from one of Amman mines in Jordan with a particle size of 26 mm. Material properties are listed in Table 1.

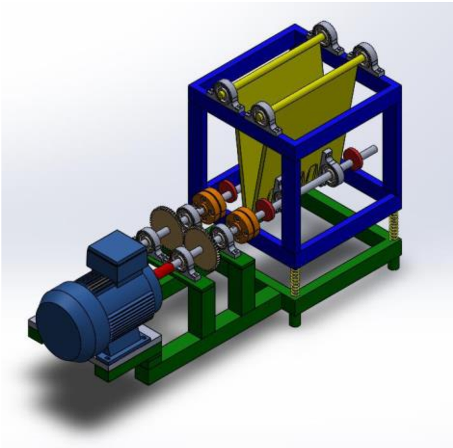
Figure 1 shows the jaw crusher scheme showing its main components, designed and implemented at Al-Balqa Applied University, indicating its main components. The design under consideration uses a single driving motor connected to a gear box. The main shaft, designated Shaft 1, connects the motor with the gear box. A rotating mass mounted on each gear shaft rotates and enforces each plate to rotate at the same angular velocity but in a different direction. This movement allows the material to be crushed when the two plates approach each other. However, when the plates move apart, the crushed material is discharged down due to the gravitational force.

It should be said that the material discharged during the crushing process is added as a raw material for the next working cycle, thereby achieving continuous crushing work.

Table 1. Properties of coarse aggregate used during experimental work [29]

Aggregate Property	Value
Specific Gravity (g/cm^3)	2.496
Bulk Density (g/ml)	1577
Absorption (AU)	0.026
Abrasion	0.31

(a)



(b)

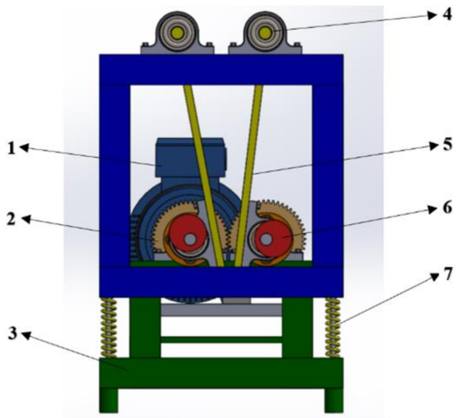


Figure 1. Scheme of the jaw crusher: (a) 3D view; (b) side view with components: 1 – motor; 2 – gear; 3 – frame; 4 – bearing; 5 – jaw; 6 – rotating mass; 7 – spring

However, it is worth noting that the jaw crusher frame is placed on four compression springs and a resin base, which control the swing amplitude of the movable jaw to avoid interference between the movable jaw and other parts, since it can be freely moved within a limited range (Fig. 1). Moreover, the compression springs also store energy during the moving jaw return stroke and release the stored energy during the working stroke to increase the crushing effect.

One of the advantages of this design is that the installation process does not need a considerable fixation of the base. Moreover, such a mechanism can be used on a large scale when crushing various hard and brittle materials. Furthermore, this mechanism provides a crushing force that exceeds the one produced by the conventional jaw crushers. Hence, higher production capacity is obtained. This mechanism contains two rotating masses on each shaft to enhance the exciter vibration to crush and break the input material. Furthermore, this mechanism does not require periodic maintenance compared to other types of jaw crushers due its simple design. Figure 2 shows the material used during crushing (coarse aggregates) before and after crushing process.

(a) (b)

Figure 2. Coarse aggregate used in current experimental work: (a) before process; (b) after process

Current jaw crusher design can be modeled with a single DOF system. It should be noted that the high vibration amplitudes of jaw crushers require the use of steel springs with a very low damping ratio. Therefore, damping in the considered vibrating system can be neglected. The equation of motion of a vibrating jaw crusher system can be written in general form as [21]:

$$M\ddot{x} + c\dot{x} + kx = me\omega^2 \sin(\omega t). \quad (1)$$

And after neglecting the damper effect, Equation (1) becomes:

$$M\ddot{x} + kx = me\omega^2 \sin(\omega t), \quad (2)$$

where:

M – total mass of the machine, kg;
m – eccentric rotating mass, kg;
e – eccentricity, m;
ω – constant angular velocity, rad/s;
k – equivalent spring stiffness, N/m;
c – dashpot constant, N.s/m;
x – amplitude of vibration, m

3. Results and discussion

Several experiments are carried out to study the impact of both the rotating mass and the jaw crusher angle on each of the produced particle sizes and the reduction ratio when varying the motor speed from 1500 to 2500 rpm. Figure 3 shows the effect of different rotating masses used (460 and 510 g) on the particle sizes produced (19, 12.5, 9.5, and 4.75 mm) for the considered motor speed variation at a jaw crusher angle of 18.5°. It can be observed that increasing the rotating mass reduces the mass obtained in the case of large particles (19 and 12.5 mm) and increases the mass of small particles (9.5 and 4.75 mm) for the considered speed variation, as shown in Figure 3.

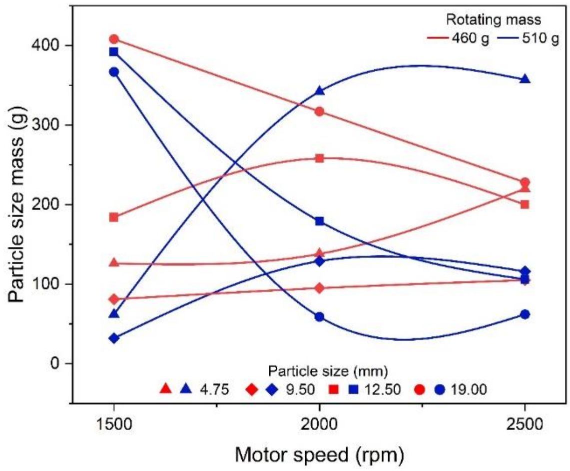


Figure 3. Effect of motor speed and different types of rotating masses at jaw crusher angle of 18.5° on the mass produced of each particle size: 19, 12.5, 9.5 and 4.75 mm

It can also be observed that larger particle sizes (19 and 12.5 mm) are obtained at a speed of 1500 rpm, regardless of the rotating mass used during experiments. However, as the engine speed increases, a significant amount of particles with a size of 9.5 and 4.75 mm is produced. It can be clearly seen that operating at a speed of 2000 rpm has a significant effect on all sizes, while increasing the speed from 2000 to 2500 rpm has almost little change. Generally, increasing the rotating mass reduces the size of the larger particles (19 and 12.5 mm) and increases the amount of smaller particles (9 and 4.75 mm) for all rotating masses used, as shown in Figure 3.

A similar trend is observed when investigating the effect of different rotating masses (460 and 510 g) on the mass of particle sizes when changing the motor speed of 1500, 2000, and 2500 rpm at a jaw crusher angle of 13.5°, as depicted in Figure 4. That is, for particle sizes of 19 and 12.5 mm, the heavier rotating mass induces the considerable large amounts for both rotating masses considered at a speed of 1500 rpm, as shown in Figure 4. Moreover, the use of 460 g rotating mass results in smaller particles, as presented in Figure 4. It should be noted that operating at a speed of 2000 rpm has an obvious impact on each particle type for both of the rotating masses considered.

The effect of the jaw crusher angle is studied for each particle size at different motor speeds when using 460 g rotating mass as presented in Figure 5. It is clearly seen that the angle effect is obvious at a speed of 2000 rpm. However, this effect results in larger particles at an angle of 18.5° and smaller particles at an angle of 13.5°, respectively (Fig. 5). Different angles will not result in obvious change in the mass for each particle size at maximum and minimum operating speeds.

However, it has been found that the jaw crusher angle of 18.5° plays an important role when using a rotating mass of 510 g for motor speeds considered, as depicted in Figure 6.

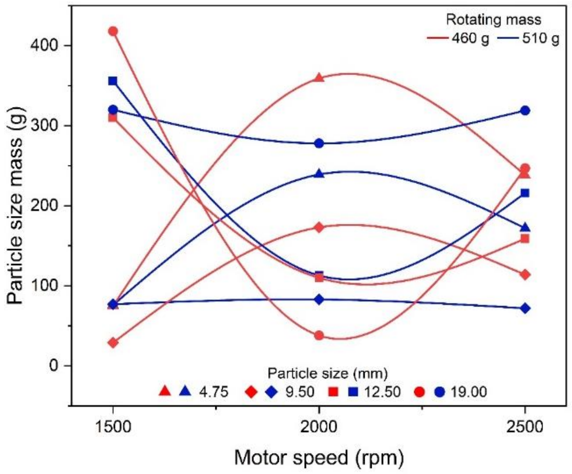


***Figure 4.** Effect of motor speed and different types of rotating masses at jaw crusher angle of 13.5° on the mass produced of each particle size: 19, 12.5, 9.5 and 4.75 mm*

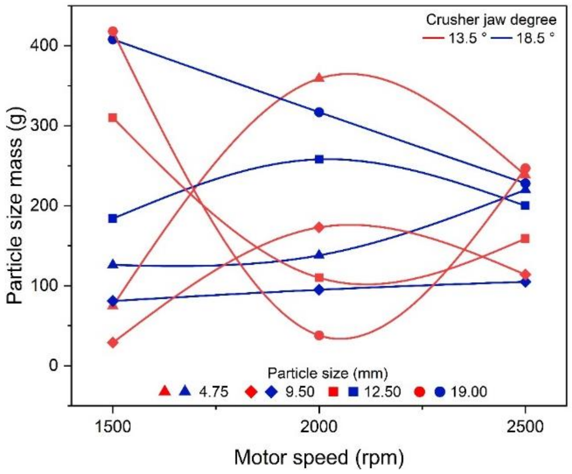


***Figure 5.** Effect of motor speed and different rotating mass types with a 460 g of rotating mass on the mass produced of each particle size: 19, 12.5, 9.5 and 4.75 mm*

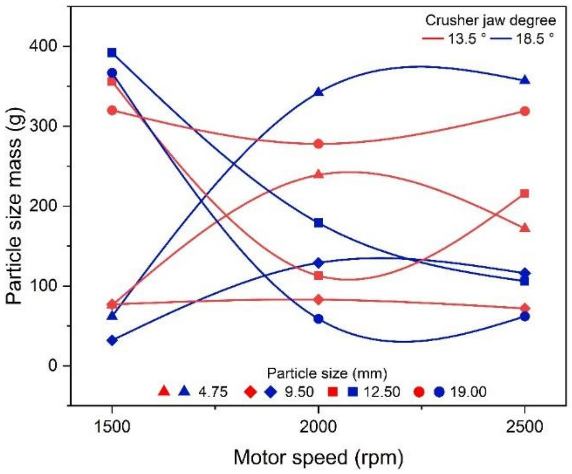


***Figure 6.** Effect of motor speed and different rotating mass types with a 510 g of rotating mass on the mass produced of each particle size: 19, 12.5, 9.5 and 4.75 mm*

Again, it should be noted that the change in mass of each particle size is much noticeable at an operating speed of 2000 rpm.

Figure 7 illustrates the relation between the crushing process time for the rotating mass of 460 and 510 g at jaw crusher angles of 18.5° and 13.5°, respectively.

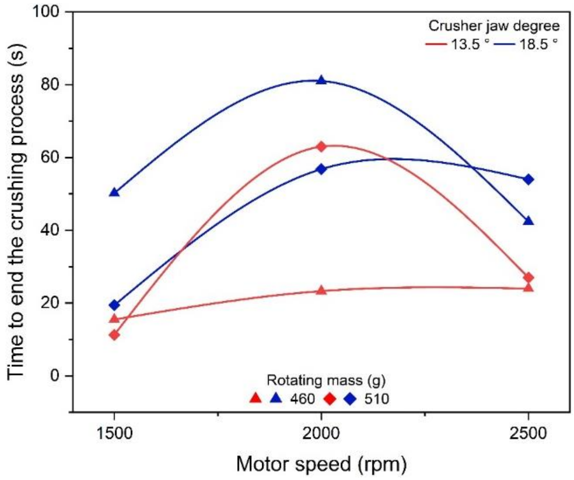


***Figure 7.** Time necessary to complete the crushing process for different jaw angles: 18.5° and 13.5°*

For the 18.5° angle case, at 1500 and 2000 rpm, an increase in the rotating mass leads to an increase in the process time, whereas at 2500 rpm both types of rotating masses have the same time. However, for the 13.5° case, it should be noted that the process time when using a rotating mass of 510 g increases sharply and reaches 63 s, although the same process time is required at a speed of 2500 rpm.

When studying the effect of the jaw crusher angle on the time necessary to complete the crushing process for 460 and 510 g, the speeds of 1500, 2000, and 2500 rpm are considered (Fig. 8). Generally, the time increases if the motor speed increases from 1500 to 2000 rpm for all considered angles and rotating masses. It should be noted that when using a mass of 460 g, the time corresponding to the angle of 18.5° is greater than the time measured in the experiments for the 13.5° case for all considered speeds. However, for the results relating to the mass type of 510 g, the measured time is almost the same, except for the motor speed 2500 rpm, when it is much longer for the 18.5° case.

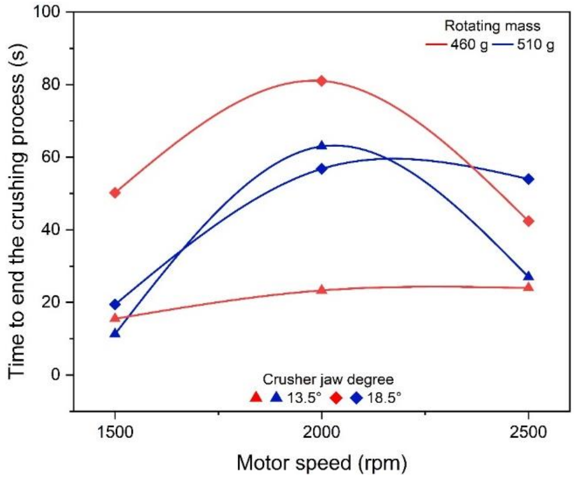


***Figure 8.** Time necessary to complete the crushing process for different rotating masses: 460 and 510 g*

The effect of motor speed and rotating mass on the reduction ratio of all considered particle sizes is investigated at an angle of 18.5° as shown in Figure 9. Maximum reduction ratio is observed at a speed of 1500 rpm for particles with a size of 19 and 12.5 mm, whereas it is clearly observed at a speed of 2500 rpm for the remaining particle sizes considered.

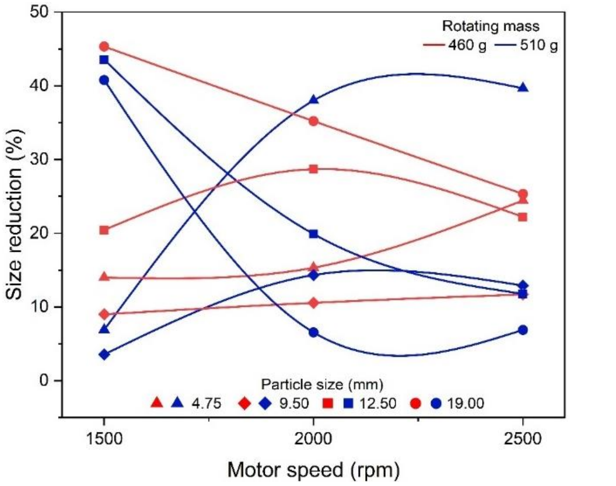


Figure 9. Effect of motor speed and different rotating mass types at jaw crusher angle of 18.5° on the size reduction obtained for each particle size: 19, 12.5, 9.5 and 4.75 mm

However, it should be noted that the rotating mass of 510 g results in the largest reduction ratio change, especially at 2000 rpm.

It has been found that the rotating mass of 460 g is optimal for all particle sizes considered when using a jaw crusher angle of 13.5° as shown in Figure 10. It should be said from the results obtained at an angle of 18.5° that the maximum reduction ratios are observed at a speed of 1500 rpm for particle sizes of 19 and 12.5 mm and at and at 2500 rpm for particle sizes of 9.5 and 4.75 mm, respectively, as depicted in Figure 10. Also, reduction ratios reduce with increasing motor speed for larger particles, while they increase for smaller particles at the same speed variation.

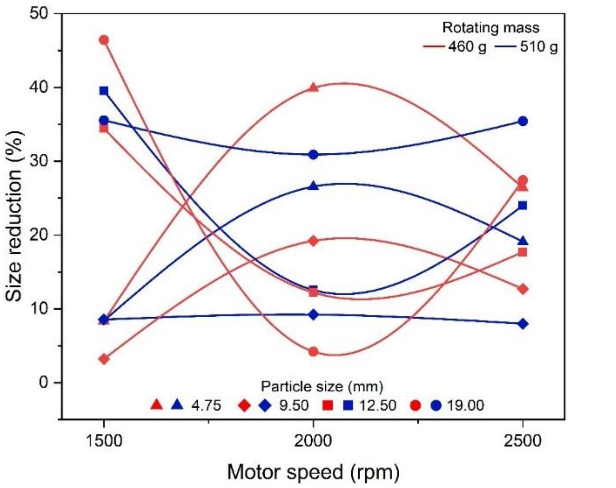


Figure 10. Effect of motor speed and different rotating mass types at jaw crusher angle of 13.5° on the size reduction obtained for each particle size: 19, 12.5, 9.5 and 4.75 mm

The effect of jaw crusher angle on each particle size reduction is studied for a rotating mass of 460 g and speed variation (1500, 2000 and 2500 rpm) as presented in Figure 11. It is clearly seen that at an angle of 13.5°, the reduction ratios are most affected regardless of the particle size, especially at 2000 rpm. It should be noted that for the same angle, if the motor speed increases, the size ratio decreases for larger particles (19 and 12.5 mm) and decreases for the remaining sizes (9.5 and 4.75 mm).

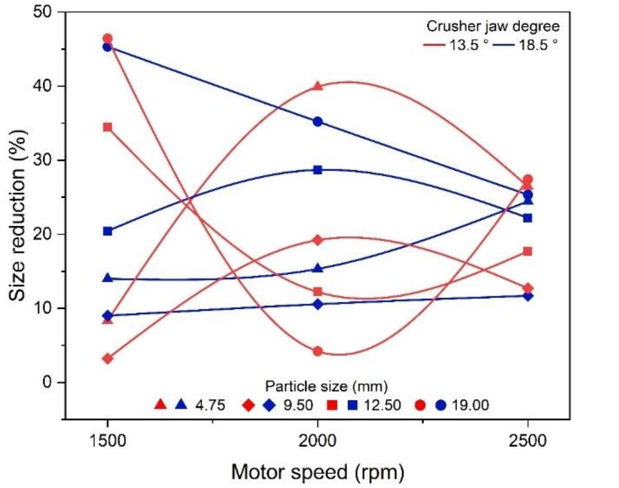


Figure 11. Effect of motor speed and different rotating mass types with a 460 g of rotating mass on the size reduction obtained for each particle size: 19, 12.5, 9.5 and 4.75 mm

The reduction ratio of all particle sizes considered and motor speed variation is investigated for different jaw crusher angles by using a rotating mass of 510 g, as depicted in Figure 12. It should be noted that the dynamics of the considered figures differs from those obtained using a rotating mass of 460 g, since the ratio of the crusher angle of 18.5° has a high impact on the reduction of all considered particle sizes.

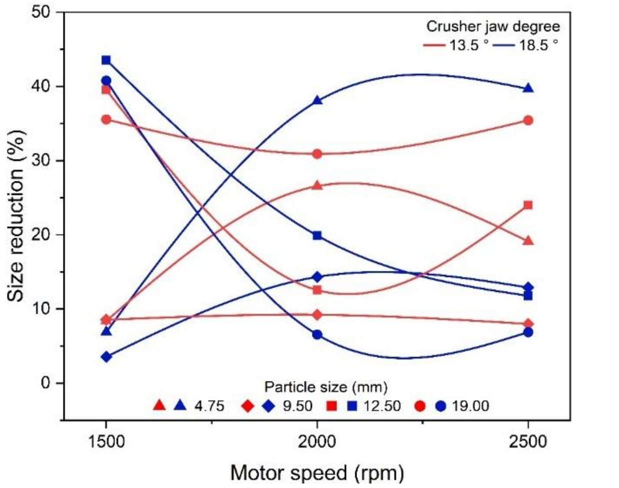


Figure 12. Effect of motor speed and different rotating mass types with a 510 g of rotating mass on the size reduction obtained for each particle size: 19, 12.5, 9.5 and 4.75 mm

The operation of the new jaw crusher design has proven an efficient and smooth crushing process on a small scale (laboratory) that can be extended to larger machines and production lines. The following step could be to increase the number of rotating mass vibrators and study their effect on the amount of produced sizes and the corresponding size reduction for a complete crushing process. This could enhance the crushing process and reduce the time required for this process. In particular, using a double moving jaw with the same rotation velocity but in different direction using single motor instead of two is an efficient solution for the crushing process, since it is less power-consuming.

In this research, we study the largest possible number of variables that could affect the crushing efficiency, such as jaw crusher angle, type of rotating mass, reduction ratios, and coarse aggregate that produces several particle sizes. Furthermore, the mass of the particles is measured and calculated.

And due to the shortage and cost of energy in Jordan, an industrial model will be implemented while conducting the same experiments on various materials needed by the local market and calculating the cost of energy consumed. It should be said that the results obtained will be compared with different crusher machines. Moreover, the effect of jaw roughness on crushing materials will be investigated, since the design and selection of a suitable jaw surface influences the crushing efficiency and can increase production.

4. Conclusions

A new jaw crusher design has been implemented at Al-Balqa Applied University. This design contains one motor connected to a gear which in turn moves the two plates with the same angular speed but in the opposite direction. The effect of several parameters, such as motor speed, jaw crusher angle and rotating mass on particle size produced and size reduction has been experimentally investigated. It should be noted that the angles and rotating mass variations are 18.5-13.5° and 460-510 g, respectively, for motor speed of 1500, 2000, 2500 rpm.

At a certain jaw angle, the mass of large particles and size reduction (19, 12.5 mm) decrease with increasing motor speed for both rotating mass types. However, the mass of particle sizes (9.5, 4 mm) increases with increasing motor speed, regardless of the jaw angle and rotating mass type. Furthermore, in general and when varying the jaw angle, it is clearly seen that there is no significant change in the resulting mass of each particle size at speeds of 1500 and 2500 rpm, since the change is well observed at 2000 rpm.

It should be noted that the size reduction results have the same dynamics as the results for particle mass. Also, it has been found that time necessary to complete the process when using 460 g at motor speed variation is much longer than the time for 510 g at the same motor speed. Moreover, the results show that the time necessary to complete the crushing process at a jaw angle of 18.5° is longer for both types of rotating masses.

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Дослідження експериментальних змінних величин вібраційної щокової дробарки

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Мета. Експериментальне вивчення різних параметрів та оптимальних умов роботи, що впливають на розмір частинок, які утворюються у вібраційній щоковій дробарці, розробленій та впровадженій в Університеті прикладних наук Аль-Балка для визначення оптимальних умов її роботи.

Методика. Кут щокової дробарки та тип обертової маси враховуються для вивчення всіх розмірів частинок і ступеня подрібнення, отриманих для трьох різних швидкостей роботи двигуна: 1500, 2000 і 2500 об/хв. Грубий заповнювач вагою 900 г з розміром частинок 26 мм подається в щокову дробарку, яка продукує кілька розмірів частинок (19, 12,5, 9,5, 4.75 і менше 4.75 мм). Надалі вимірюється маса частинок і обчислюється ступінь їх зменшення.

Результати. Виявлено, що кут щокової дробарки, тип обертової маси та швидкість роботи двигуна відіграють важливу роль як у зменшенні кількості маси, так і в зменшенні розміру кожної виробленої частинки. Крім того, було визначено, що робота зі швидкістю 2000 об/хв забезпечує значну зміну зменшення як маси, так і розміру кожного розглянутого розміру частинок.

Наукова новизна. Оригінальність цього дослідження полягає в експериментальному вивченні впливу різних параметрів на зменшення розміру частинок у вібраційній щоковій дробарці, а також у впровадженні нової конструкції, яка використовує один двигун для приводу двох пластин, що працюють з різними швидкостями та в протилежних напрямках.

Практична значимість. Отримані дані можуть бути використані для оптимізації конструкції та роботи щокових дробарок у різних галузях промисловості, у тому числі в металургійній, кар'єрній та гірничодобувній, де ці дробарки широко використовуються. Результати цього дослідження також можуть слугувати основою для майбутніх досліджень щодо зменшення розміру частинок в інших типах дробарок і подрібнювального обладнання.

Ключові слова: *щокова дробарка, подрібнення, вібрація, фрезерування, матеріал*