INVESTIGATION OF THE RELATIONSHIP BETWEEN THE BOND GRINDABILITY TEST AND THE STATIC AND DYNAMIC STRENGTH OF ROCKS

Yakup UMUCU[1*], Y. Hakan GÜRSOY[2]

[1] Eskişehir Osmangazi University, Mining Engineering Department, Eskişehir,
ORCID No : http://orcid.org/0000-0002-6317-4070
[2] Eskişehir Osmangazi University, Mining Engineering Department, Eskişehir,
ORCID No : http://orcid.org/0000-0001-8987-7818

Keywords

Grinding, Bond Work Index, Hopkinson dynamic tests, Static compressive strength

Abstract

The Bond method is widely used in the design of grinding circuits in an ore preparation plant, sizing of mills, determining power requirements, determining and measuring performance, and for materials considered for comminution. Its use as a standard is very common in the industry as it provides satisfactory results in all industrial applications. The dynamic method was developed as an alternative to static methods in determining the mechanical properties of materials. There are studies investigating the static and dynamic properties of materials and revealing the relationship between these parameters. Previously, a lot of work was done between mechanical tests and grinding. However, in these studies, the relationships were only revealed with equations. Research, which is a mechanical property closest to the grinding mechanism, was not conducted. In this study, the relationship between grinding and static and dynamic compressive strength was investigated. Dynamic compressive strength was also determined by the Hopkinson dynamic test. For the first time, the relationship between grinding and compressive strength based on the Hopkinson dynamic test was demonstrated. A relationship with a value of R^2:0.82 and 0.738 was obtained between grindability and compressive strength depending on the Hopkinson dynamic test.

KAYAÇLARIN BOND ÖĞÜTÜLEBİLİRLİK TESTİ İLE STATİK VE DİNAMİK DAYANIMI ARASINDAKİ İLİŞKİNİN ARAŞTIRILMASI

Anahtar Kelimeler

Öğütme, Bond İş İndeksi, Hopkinson dinamik test, Statik basınç dayanımı

Öz

Bir cevher hazırlama tesisindeki öğütme devrelerinin tasarımında Bond yöntemi, değirmenlerin boyutlandırılmasında, güç ihtiyacının belirlenmesinde ve performans belirleme ve ölçümünde ufalanması düşünülen malzemeler için yaygın olarak kullanılmaktadır. Tüm endüstriyel uygulamalarda tatmin edici sonuçlar sağladığı için bir standart olarak kullanımı endüstride çok yaygındır. Dinamik metot, malzemelerin mekanik özelliklerinin belirlenmesinde statik metotlar için bir alternatif olarak geliştirilmiştir. Malzemelerin statik ve dinamik özelliklerini araştıran ve bu parametreler arasındaki ilişkiyi ortaya koyan çalışmalar mevcuttur. Daha önce mekanik testler ile öğütme arasında birçok çalışma yapılmıştır. Ancak bu çalışmalarda sadece ilişkiler denklemlerle ortaya konmuştur. Hiç birisinde öğütme mekanizmasına en yakın mekanik özellik hangisinin olduğu konusunda bir araştırma yapılmamıştır. Bu çalışmada öğütme ile statik ve dinamik basınç dayanımı arasında ilişki araştırılmıştır. Dinamik basınç dayanımı da Hopkinson dinamik test ile belirlenmiştir. İlk defa öğütme ile Hopkinson dinamik teste bağlı basınç dayanımı arasında ilişki ortaya konmuştur. Öğütülebilirlik ile Hopkinson dinamik teste bağlı basınç dayanımı arasında R^2:0.82 ve 0.738 değerine sahip bir ilişki elde edilmiştir.

Araştırma Makalesi
Başvuru Tarihi : 19.08.2021
Kabul Tarihi : 18.10.2021

Research Article
Submission Date : 19.08.2021
Accepted Date : 18.10.2021

* Sorumlu yazar; e-posta : yakup.umucu@ogu.edu.tr

1. Introduction

The bond work index values determine the grinding resistance of the materials and the energy consumption. The work index of a material is expressed as the amount of energy required to reduce 80% of the theoretically infinite size of the ore below 100 microns. The Bond method is mostly used in the design of grinding circuits and mills to determine the power requirements of the mills and evaluate the performance of the operating system (Austin and Brame, 1983). Because this test for the grindability and Bond work index of materials is long and tiring, methods have been proposed by many researchers to make the process easier (Berry and Bruce, 1966; Smith and Lee, 1968; Horst and Bassarear, 1976; Kapur, 1970, Karra, 1981; Magdalinović, 1989). Some of these methods require a Bond mill, while others use any laboratory mill.

However, the methods presented in all these studies require a series of studies based on grinding and sieve analysis, and also require experienced and skilled personnel. Almost all of these grinding-based experiments required a lot of work and time. Because of the difficulty in determining of this index, alternatives to the standard method have been developed by many researchers. For example, Deniz and Özdağ (2003) have investigated the effect of elastic parameters on grinding and the relationship between them.

As it is known, the blasting technique, primary crushing, secondary crushing, and grinding stages applied in both ore production and excavation work are size reduction processes. Compression, tensile, and shear stresses that are effective on the rock mass, rock fragment, and rock sample during the size reduction processes are effective in the specified activities. Since there are common parameters that are effective in all activities, it can be thought that some of the experimental studies carried out on rocks and samples are related to each other, and it may be possible to predict the results of the tests, which are more difficult and costlier, with simpler and more economical test methods (Bearman, Briggs and Kojovic, 1997).

The Hopkinson pressure bar system was first proposed by Hopkinson (1914) and developed by Kolsky (1949). Researchers have widely used the Hopkinson pressure bar system to study the behavior of solid materials under dynamic pressure at high strain rates (Kumar, Mies, and Pengjun, 2004; Xia, Nasseri, Mohanty, Lu, Chen and Luo, 2008; Dai, Xia and Tang, 2010).

Dynamic testing techniques in different experimental equipment stand out with its advantages, such as repeatability of measurements and relatively accurate results. There are two pressure bar assemblies for the Hopkinson pressure bar experiment; The Split Hopkinson pressure bar (SHPB) and the single Hopkinson pressure bar. Although both techniques are the same in principle, the dynamic load is first applied through two long bars and, secondly, it is made directly by a striker bar. SHPB is more widely used. SHPB is more widely used. The striking bar is accelerated by methods such as compressed air, pendulum, or explosive, and the impact is produced (Tüfekçi, 2008).

Yavuz, Tüfekçi, Kayacan and Cevizci (2012), state that the mechanical strength of the rock against the resistance of a grinding relationship can be expected. If this relationship can be identified correctly, the prediction of Bond Index Values and breakage characteristics will be of great importance from the material strength properties because of materials.

In previous studies, the relationships between static tests and grindability were investigated for rocks. In this study, the relationship between the Hopkinson test, which is in the dynamic test group, and grindability was investigated. For the first time in this study, static or dynamic tests were used represent the grinding mechanism well. For this purpose, first static and dynamic tests were carried out on the samples, and then grindability tests were conducted. As a result, the relationship between dynamic testing and grindability was found to be higher.

The aim of this study is to investigate the behavior of rock material under dynamic and static conditions and establish relations between these properties and Bond Grindability, Bond Work Index, and the research has been prepared by analyzing in accordance with publication ethics.

2.Background

2.1. The Standard Bond Grindability Test

The most widely known measure of grindability is Bond Work Index (BWI) which was defined as the resistance of the material to grinding and quantified the specific work input (kWh/t) required to reduce the material from theoretically infinite size to 80% passing 0.106 mm (Bond, 1961; Yap, Sepulude, and Jauregui, 1982).

Deniz and Özdağ (2003) carried out ultrasonic wave velocity and Bond Work Index experiments using sedimentary and volcanic rock samples. Dynamic elastic properties (Young's modulus, bulk modulus and shear modulus) of the samples were determined by ultrasonic wave velocity experiment. The correlation of the values they obtained was done by the rock samples of both groups separately. Accordingly, for both sedimentary and volcanic rock samples, they determined that while the dynamic Young's modulus and shear modulus increased, the grindability decreased linearly, while the Bond work index increased exponentially. They found that grindability decreased exponentially with the increase of the bulk modulus, while the Bond work index increased linearly.

In the determination of the physico-mechanical and mechanical properties of the materials, Dynamic methods have been proposed as an alternative method to the static methods. They tried to determine the grinding energy and the breaking behavior of rocks by using the weight drop method in their experiments (Bearman et al., 1997).

2.2. Dynamic Testing Method

The mechanical behavior of materials under high deformation rates is quite different from the mechanical behavior observed under low strain rates. For this reason, it is necessary to determine the mechanical behavior of materials under dynamic loads for many engineering applications. While the deformation rate is less than 1 s^{-1} in the mechanical tests performed with conventional servo-hydraulic machines under quasi-static loads, the deformation rate obtained in the Split Hopkinson Compression Rod experimental setup, in which dynamic loads are applied, is between 10^2 s^{-1} and 10^4 s^{-1} (Yavuz et al.,2012).

Two main problems were encountered in the experiments carried out at high deformation rate with various mechanical test devices. The first of these problems was the obtaining of very little detailed data. The other problem was that the changes in the samples could not be well controlled. Kolsky (1949) has come up with a clever solution to these two problems. Instead of applying a direct impact to the sample, he placed the sample between two elastic compression bars and applied an impact to one of these bars.

The most important feature of the split Hopkinson Compression Rod experimental setup is that it generates a stress-strain graph in the range of deformation rates of 10^2 s^{-1} - 10^4 s^{-1}. However, it is not possible to obtain such a stress-strain / transformation changing graph under dynamic loads with conventional impact tests. In addition, many material types such as metal, ceramic and polymer can be tested in the SHBP experimental setup (Tüfekçi, 2008).

3.Materials and Experimental Methods

3.1. Materials

As a basis for this study, dynamic and static strength were initially measured for the five samples of sedimentary origin and the two samples of metamorphic origin. Secondly, Standard Bond Grindability tests were carried out and work indices (Wi) were calculated. The names and locations of the rocks selected for this study were given in Table 1 and the chemical properties of the samples were presented in Table 2.

Table 1.

Name and Location of The Rocks Selected for This Study (Yavuz et al., 2012).

Rock Type	Location
Limestone –I	Bilecik
Limestone –II	Burdur
Limestone –III	Antalya-Finike
Limestone –IV	Burdur-Karamanlı
Travertine	Burdur-Bucak
Marble-I	Muğla
Marblee -III	Afyon

3.2. The Analyzed Scanning Electron Microscope (SEM)

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the surface topography and composition of the sample. The electron beam is scanned in a raster scan pattern, and the position of the beam is combined with the intensity of the detected signal to produce an image. In the most common SEM mode, secondary electrons emitted by atoms excited by the electron beam are detected using a secondary electron detector (Everhart-Thornley detector). The number of secondary electrons that can be detected, and thus the signal intensity, depends, among other things, on specimen topography. Some SEMs can achieve resolutions better than 1 nanometer. (McMullan, 2006).

SEM and mineralogical analyses were conducted as they give an idea about the grindability of the samples used in the study. SEM images obtained for analysis are shown in Figure 1-7. In addition, the geological analysis of the samples also contributed to the SEM analysis.

Table 2.

Chemical Composition of Samples Used in Experiments

Oxides	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	Na_2O	K_2O	LOI
Limestone –I	53.50	1.25	0.03	0.55	0.40	0.01	0.01	0.00	42.03
Limestone –II	54.55	0.26	0.33	0.32	0.31	0.03	0.01	0.01	42.07
Limestone –III	57.28	0.15	0.01	0.12	0.23	0.02	0.01	0.01	42.20
Limestone –IV	55.42	0.08	0.35	0.22	-	0.03	0.01	0.01	42.15
Travertine	54.55	0.26	0.29	0.32	0.31	0.02	0.01	0.01	42.73
Marble-I	55.43	0.52	0.13	0.04	0.28	0.00	0.01	0.00	42.02
Marble -III	55.72	0.27	0.07	0.03	0.22	0.00	0.01	0.00	42.13

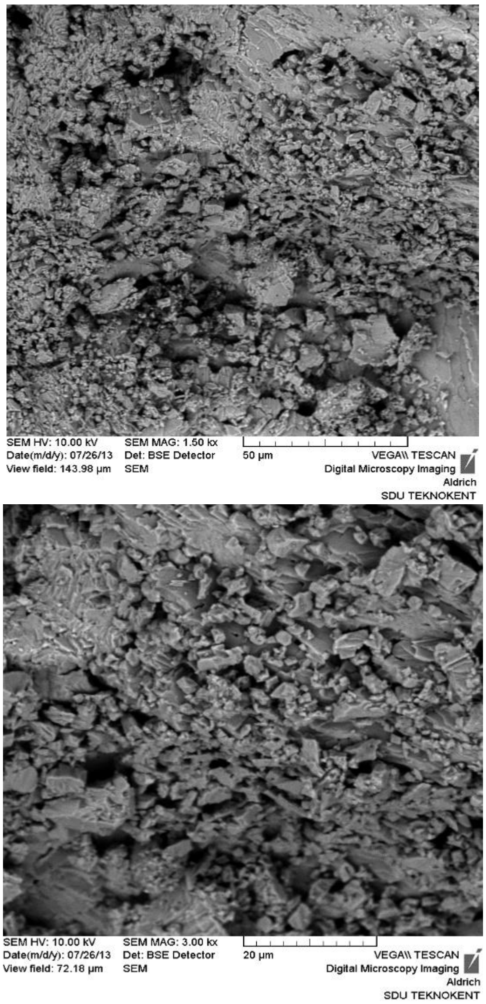

Figure 1. SEM Photographs of Limestone-I Sampling in 50 and 20 Microns

According to SEM analyses and geological analyses, it was observed that the structure is mostly found to contain Ca and rarely contains Si. However, an open pore and the beginning of the first fracture on the surface can be observed for Limestone-I.

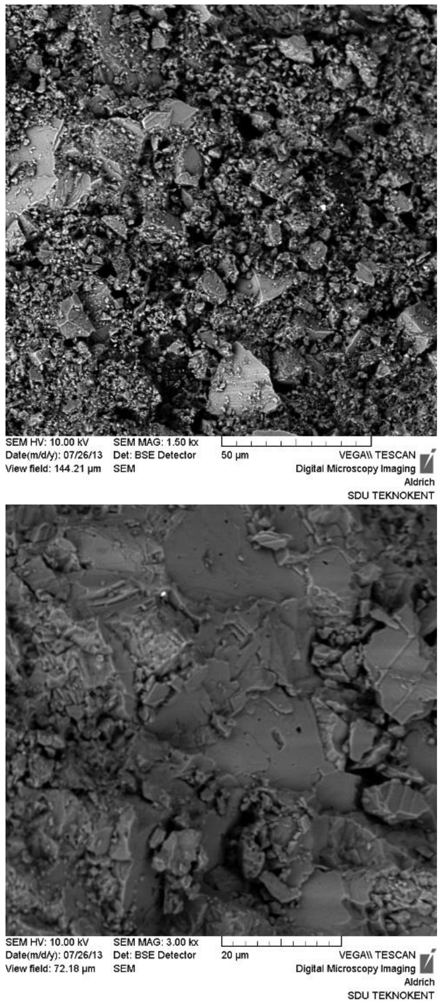

Figure 2. SEM Photographs of Limestone-II Sampling in 50 and 20 Microns

In SEM analyses, it has been observed that Limestone-II fracture planes of Si content are low in porosity and thereby Limestone-II fracture planes only occur in Ca regions which is rich in content. In addition, it is said that the minerals that fill in the cracks are affected during the breakage process.

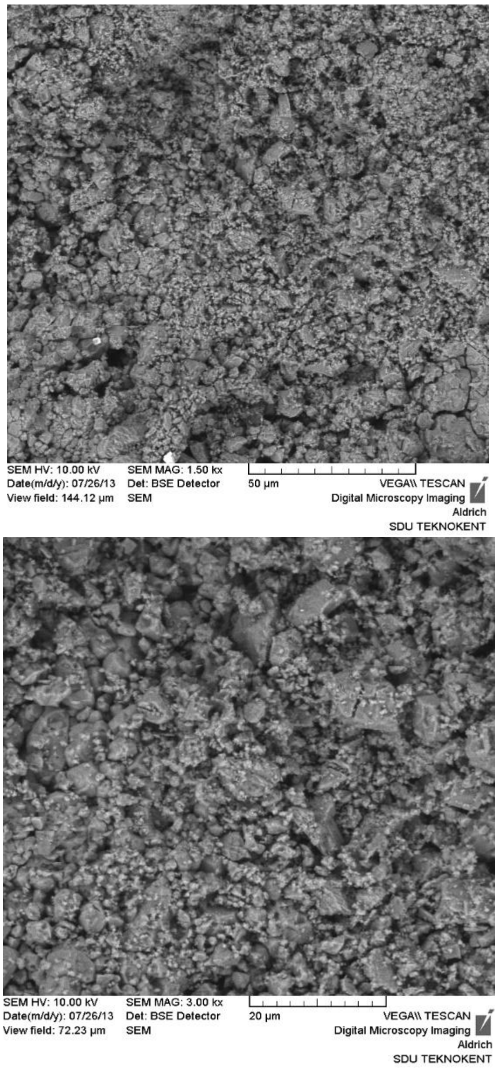

Figure 3. SEM Photographs of Limestone-III Sampling in 50 and 20 Microns

In the SEM studies for Limestone-III, it has been observed that it is rich with Ca content towards the internal structure of the rock, but the surface appears to occur in a broken-crack formation.

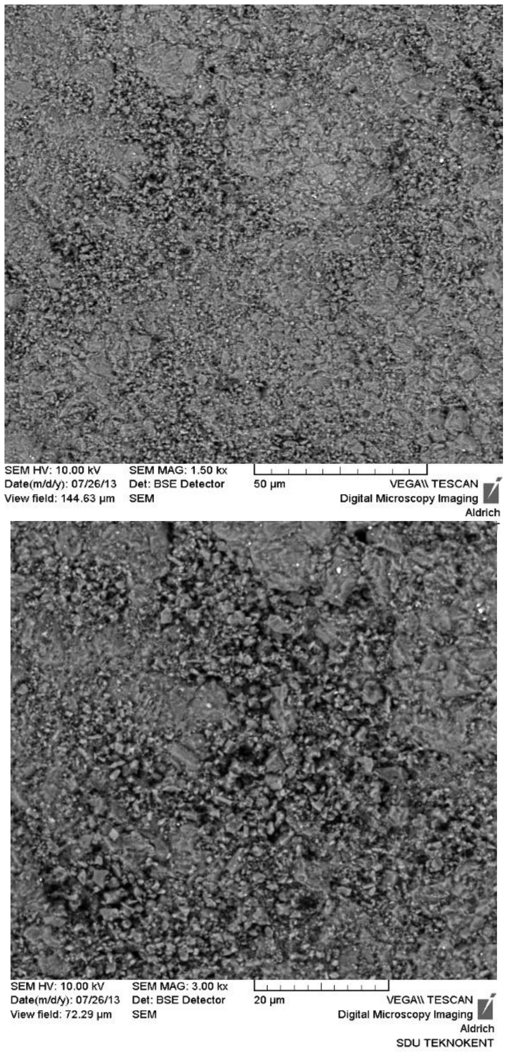

Figure 4. SEM Photographs of Limestone-IV Sampling in 50 and 20 Microns

In the studies, the Si content in the limestone-IV has been observed. In addition, the majority of the rock is consists of Ca minerals, which is coarse and breaks the crystal structure of Ca realization of these grains, which causes the negative impacts on the results.

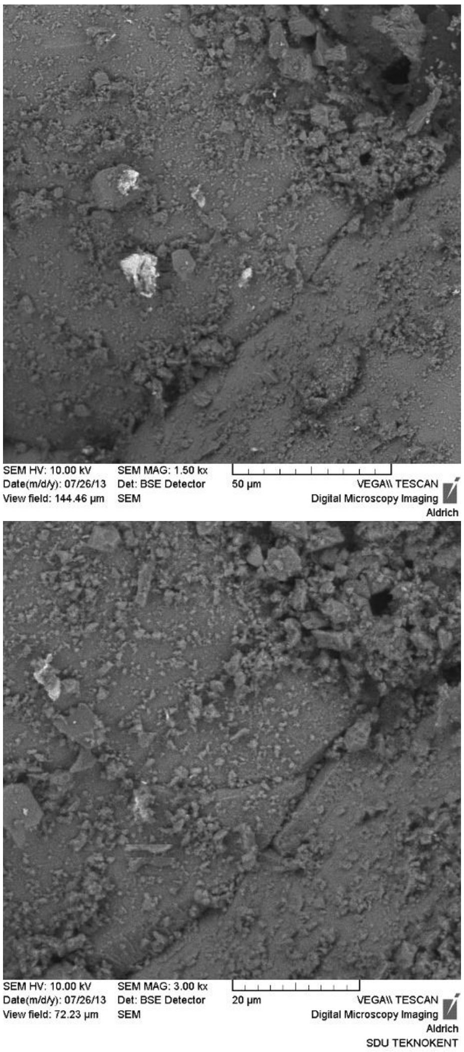

Figure 5. SEM Photographs of Travertine Sampling in 50 and 20 Microns

In the SEM analysis conducted on Travertine, it has been observed that fine Si grains and have a porous structure. On the other hand, the rock may have a porous structure. However, quartz grains detected in fine grain size may make comminution difficult. It will be harder for the material to break when there are small particles in the pores during grinding.

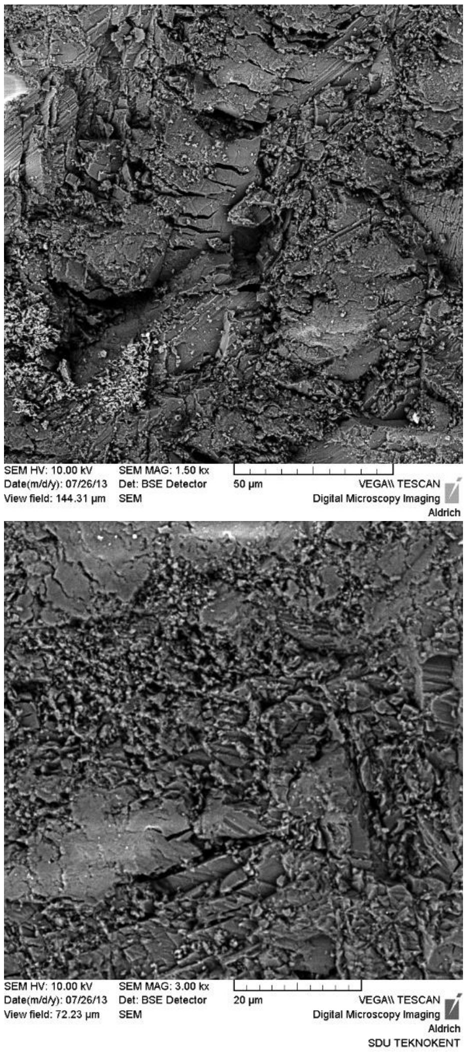

Figure 6. SEM Photographs of Marble-I Sampling in 50 and 20 Microns

In SEM studies on Marble-I, it has been observed that Marble-I has the structure of crystalline rock and ruptures occur along the crystal planes. However, fine-grained products are identified as a result of a broken crack formation.

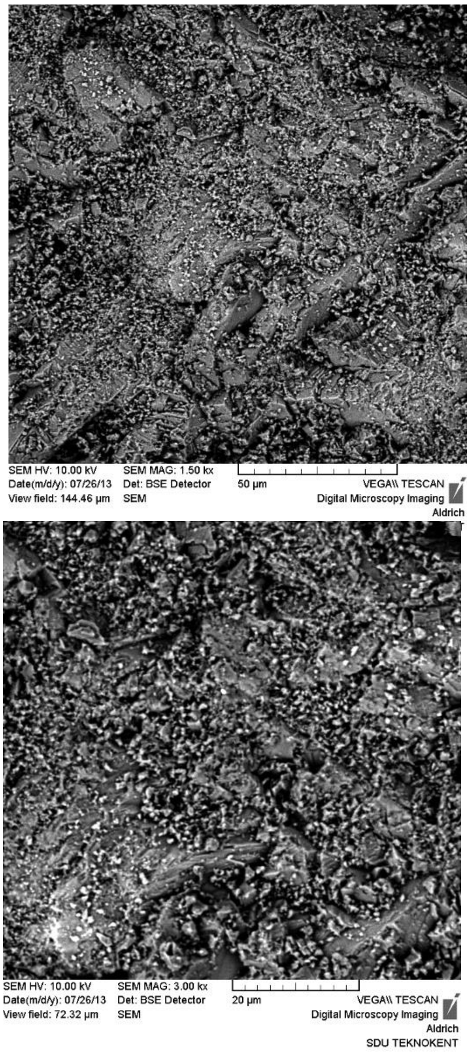

Figure 7. SEM Photographs of Marble III sampling in 50 and 20 Microns

In studies, it has been observed that Marble-III has a similar structure to Marble-I, but it crystallizes in small pieces. As a consequence, the fine particles are produced as a result of disintegration, which causes lower friability.

3.3. The Test of Standard Ball Mill Bond Grindability

The samples, from which SHPB measurements are taken, are crushed in a laboratory scale jaw crusher, and then the standard Bond grindability test is performed. The Bond work index values (Wi) are calculated from equation (1) below.

The standard Bond grindability test is a closed-cycle dry grinding in a standard ball mill (30.5x30.5 cm) and screening process, which is carried out until a steady state condition is obtained (Figure 8). This test was described as follows (Bond and Maxson, 1943; Yap et al., 1982; Austin and Brame, 1983; Magdalinovic, 1989).

The material, which was under 3.35 mm, was packed into a 700 cc volume using a vibrating table. This is the volumetric weight of the material to be used for grinding tests. For the first grinding cycle, the mill is started with an arbitrarily chosen number of mill revolutions. At the end of each grinding cycle, the entire product is discharged from the mill and is screened on a test sieve (P_i). The standard choice for P_i is 106 microns. The oversize fraction is returned to the mill for the second run together with fresh feed to make up the original weight corresponding to 700 cc. The weight of product per unit of mill revolution, called the ore grindability of the cycle, is then calculated and used to estimate the number of revolutions required for the second run to be equivalent to a circulating load of 250%. The process is continued until a constant value of the grindability is achieved, which is the equilibrium condition. This equilibrium condition may be reached in 6 to 12 grinding cycles. After reaching equilibrium, the grindabilities for the last three cycles are being averaged. The average value was taken as the standard Bond grindability (G_{bg}).

The products of the final three cycles are combined to form the equilibrium rest product. A sieve analysis is carried out on the material and the results are plotted in order to find the 80% passing size of the product (P_i).

Figure 8. Standard Bond Ball.

$$W_i = 1.1 * \frac{44.5}{P_i^{0.23} * G_B^{0.82} * \left[\left(10/\sqrt{P_{80}}\right) - \left(10/\sqrt{F_{80}}\right)\right]} \quad (1)$$

Where W_i is the work index (kwh/t); P_i, screen size at which the test is performed (106 µm); G_B, Bond standard ball mill grindability, net weight of ball mill product passing sieve size P_i produced per mill revolution (g/rev); P_{80}, sieve opening which 80% of the product passes (µm) ; F_{80}, sieve opening which 80% of the feed passes (µm).

Table 3.

Grindability Properties of Using Rocks

Rock Name	Wi (Kwh/t)	G (g/rv)
Limestone –I	12.56	1.39
Limestone –II	11.99	1.54
Limestone –III	6.30	3.28
Limestone –IV	15.02	1.23
Travertine	7.66	2.73
Marble-I	8.71	2.52
Marble -III	7.17	3.39

Although the origins of rocks used in experimental studies are the same, Bond grindability and Bond Work Index values are different. Bond grindability of Limestone-III rock was determined as easy. The main reason for this is the rock's high porosity.

In experimental studies, the Bond Grindability of Lim-IV rock is the most difficult of the samples. The biggest reasons for the low Bond grindability is the porosity of the sample, which is based on the solid rock texture.

Although the rocks of Marble-I and Marble-III are the same type, there are differences in comminution characteristics. The reason for this condition is that Marble-III has a bigger crystals structure than Marble-I.

3.4. Dynamic Testing Conditions

Laboratory tests were used in this study to take Figure 9. For each rock type testing group, seven samples were prepared by water jet cutting. Samples for dynamic tests were cylindrical in shape with diameter 18 mm and thickness 11 mm. The ratio of sample thickness to diameter was about 0.6, which was favorable to reduce the inertial effect and end effector. Sample faces were parallel to each other and perpendicular to the central vertical axis. In order to reduce the effect of friction on the boundary measured strength, the bar-sample interfaces were lubricated with grease. A thin cupper (Cu 11000) disc in each test was used as a pulse shaper and was placed on the center of the impact surface of the incident bar with a light coating of grease. The round cupper disc used was 6 mm in diameter, 0.8 mm in thickness and was annealed in an oven for 2 hours at 400 ^{o}C (Yavuz et al., 2012).

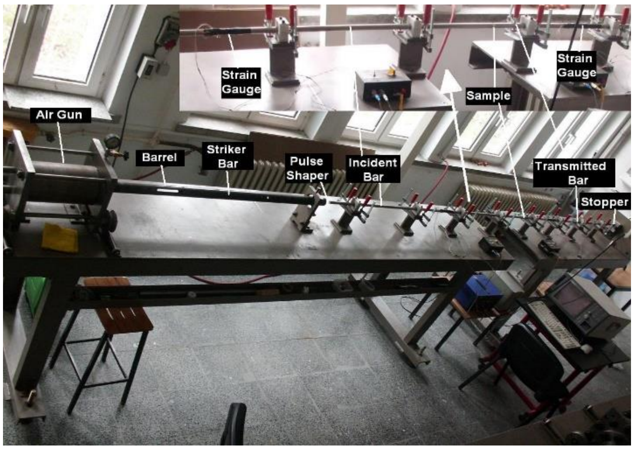

Figure 9. SHPB Equipment Used in This Study for Dynamic Compression Testing (Yavuz et al., 2012).

The strain rate was calculated from the flat level of the strain rate-time curve for all samples, and the average values with minimum and maximum values for each rock type are given in Table 3.

Table 4.

Static and Dynamic Compressive Strength of Rocks (Yavuz et al., 2012).

Rock Name	Static compressive strength (kg/cm^2)	Dynamic compressive strength (kg/cm^2)
Limestone –I	126.00	225.00
Limestone –II	119.00	220.00
Limestone –III	43.00	103.00
Limestone –IV	100.00	185.00
Travertine-II	36.00	110.00
Marble-I	60.00	118.00
Marble -III	54.00	125.00

4. Results and Discussion

From the test results, correlations for all samples were obtained for different geological origins. Later, relationships between static and dynamic compressive strength values of rocks and Bond grindability and work index are shown in Fig. 10-11.

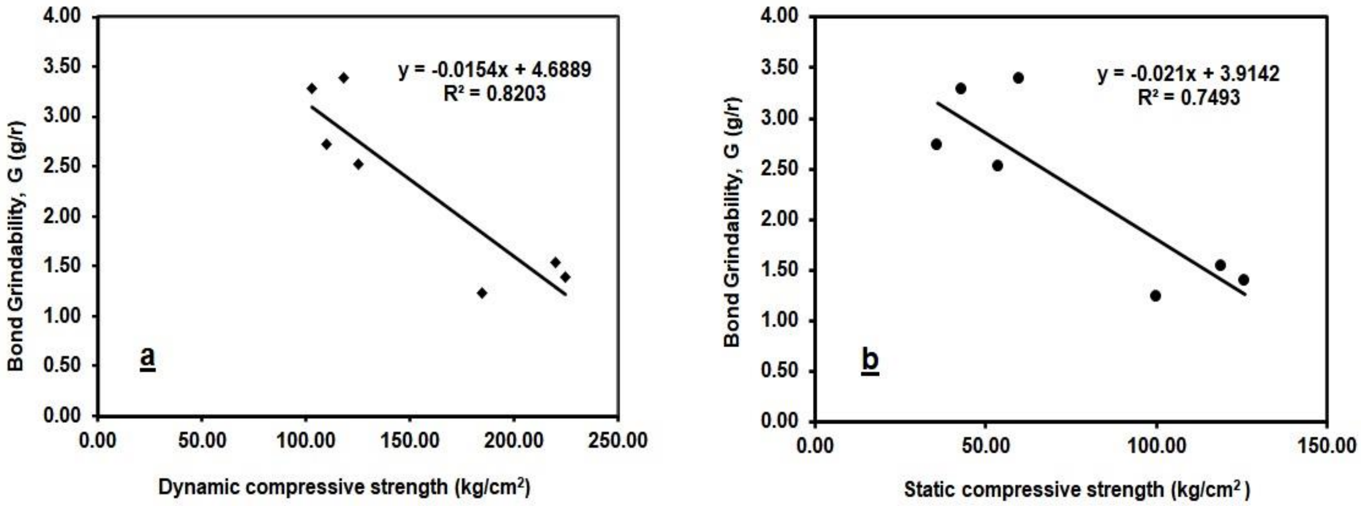

Figure 10. a) Relationships Between Gbg and Static Compressive Strength Values of rocks

b) Relationships Between Gbg and Dynamic Compressive Strength Values of rocks.

$G_{bg}= -0.0154\ DCS + 4.6889 \qquad R^2=0.820$ (2)

$G_{bg}= -0.021\ SCS + 3.9142 \qquad R^2=0.749$ (3)

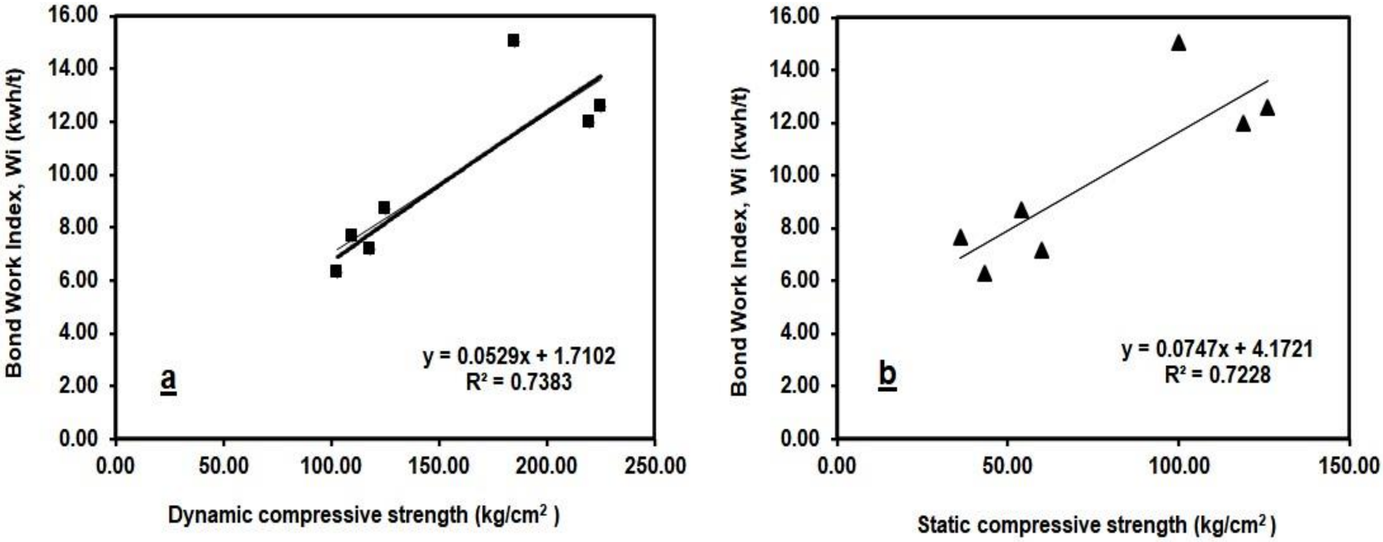

Figure 11. a) Relationships Between Bond Work Index and Static Compressive Strength Values of rocks

b) Relationships Between Bond Work Index and Dynamic Compressive Strength Values of rocks.

$BWI = 0.1144\ DCS^{0.884} \qquad R^2=0.738$ (4)

$BWI = 0.8673\ SCS^{0.5643} \qquad R^2=0.723$ (5)

When the two graphs are observed, the relationship between Bond Grindability and dynamic compressive strength has a higher correlation than static compressive strength. The most important reason for the relationship is that the dynamic compressive strength is greater; more effective than the static compressive strength in the tumbling mill.

5. Conclusions

The purpose of this study was to show the correlation between grindability and dynamic parameters.

In this study, measurements were taken from five sedimentary and two metamorphic samples, totaling seven samples. The best correlation was found between grindability and dynamic compressive strength, with R^2=0.820 for G_{bg} and R^2=0.827 for BWI.

In the dynamic test results, it was determined that the stress increase per unit time in the samples tested under the same conditions was higher in the samples of high strength than in the samples of low strength.

It has been determined that samples with massive structures have higher dynamic and static strength values, while samples with crystalline structures have low strength values. Similarly, the same situation appeared in the grindability values. The samples had a massive and homogeneous mineralogical cement, which was found to have high resistance to comminution. The energy required for comminution is higher. It can be expressed as the abrasion of materials by rubbing against each other. For this reason, finding a correlation between dynamic compressive strength and grindability is realistic.

When the dynamic compressive strength values were compared, it was determined that the samples with homogeneous and massive cement structures were higher. Similar behavior was also observed in static compressive strength values. The reason for the high values in materials which have homogeneous and massive cement structure is that fragment ruptures or breakage occur at the bond points with other minerals in small amounts or on fractured-crack surfaces with small amounts. On the other hand, the breakage was as large as their diameters due to the crystalline structure of marble samples. In the travertine sample, this situation is limited to the distances between the pores. Breakage occurred along the crack surfaces.

The dynamic method has many advantages, because of its ease of use and the relatively short time required compared to the static method. Furthermore, dynamic methods are better than static methods because grinding is also a moving process, which means that dynamic methods are better.

Acknowledgement

Researchers, in "Predicting the Dynamic Compressive Strength of Carbonate Rocks from Quasi-Static Properties" of Yavuz H., Tüfekçi K., Kayacan R., Cevizci H. (2013) published in Experimental Mechanics (DOI 10.1007/s11340-012-9648-7,53(3), 367-376) would like to thank for using the Hopkinson test data and them as samples in Bond Grindability experiments and in regression analyzes in this study.

Researchers would like to thanks for mineralogical analyzes to Assoc. Prof. Dr. Şemsettin Caran.

Author Contributions

In this article, Yakup UMUCU and Y. Hakan GÜRSOY proposed the concept, designed the research, discussed the results and reviewed the manuscript.

Conflict of Interest

There is no conflict of interest.

References

Austin, L.G. & Brame, K. (1983). A comparison of the Bond method for sizing wet tumbling ball mills with a size-mass balance simulation model. *Powder Technol. 34, 261–274.* doi: https://doi.org/10.1016/0032-5910(83)87059-4

Bearman, R.A., Briggs, C.A. & Kojovic, T. (1997). The Application of Rock Mechanics Parameters to the Prediction of Comminution Behaviour. *Minerals Engineering, 10, 3, 255-264.* doi: https://doi.org/10.1016/S0892-6875(97)00002-2

Berry,T.F. & Bruce., R.W. (1966). A simple method of determining the grindability of ores. *Can. Min. J., vol, 80, pp. 63-65.*

Bond, F.C. (1961). Crushing and Grinding Calculations. *British Chemical Engineering, 6, 378-385, 543-548.*

Bond, F.C. & Maxson, W.L. (1943). Standard grindability tests and calculations. *Trans. Soc. Min. Eng., AIME 153, 362–372.*

Dai, F., Xia, K. W. & Tang, L Z. (2010). Rate dependence of the flexural tensile strength of Laurentian granite. *International Journal of Rock Mechanics and Mining Sciences, 47 (3), pp. 469-475.*

Deniz, V. & Özdağ, H., (2003). A new approach to Bond grindability and work index: dynamic elastic parameters. *Minerals Engineering, vol. 16, 211–217. doi: https://doi.org/10.1016/S0892-6875(02)00318-7*

Horst, W. E. & Bassarear. J. H. (1976). Use of simplified ore grindability technique to evaluate plant performance. *Trans. SME- AIME. Vol. 260. 348-351.*

Karra, V. K., (1981). Simulation of Bond grindability tests. *CIM Bull., 74, pp. 195-199*

Kapur, P. C. (1970). Ana1ysis of the Bond Grindability Test. *Trans. IMM, Vol. 79, pp. C-103-108.*

Kolsky, H. (1949). An investigation of the mechanical properties of materials at very high rates of strain. *Proc. R. Phys. Soc. B 62, 676–700.*

Kumar, A., Mies, L.T.S. & Pengjun, Z. (2004). Design of an impact striker for a split Hopkinson pressure bar. *J., Inst. Eng. 44(1), 119–130.*

Magdalinovic, N., (1989). A procedure for rapid determination of the Bond work index. *Int. J. Min. Process. 27, 125–132.*

Mcmullan, D. (2006). Scanning electron microscopy 1928–1965. *Scanning, 17 (3), 175. doi:*

Nematollahi, H., (1994). New size laboratory ball mill for Bond work index determination. *Min. Eng. (April), 352–353.*

Smith, R.W. & Lee, K.H., (1968). A comparison of data from Bond type simulated closed-circuit and batch type grindability tests. *Trans. Soc. Min. Eng., AIME 241, 91–99.*

Sisman, H., Altintas, M. & Ozturk, I., (1990). Relationships between seismic wave velocities and rock parameters in rock mechanics (in Turkish). *II. Rock mechanic symposium, Ankara, pp. 221–237.*

Tüfekçi, K., (2008). Gerinim hızının kortikal kemiğin mekanik özellikleri üzerindeki etkisinin incelenmesi. Doktora tezi, *Süleyman Demirel Üniversitesi, Fen bilimleri Enstitüsü, Isparta.*

Xia,K., Nasseri, M.H.B., Mohanty,F.Lu,B., Chen,R. & Luo, S.N., (2008). Effects of microstructures on dynamic compression of barre granite. *International Journal of Rock Mechanics and Mining Sciences, 45 (6), pp. 879-887. doi: https://doi.org/10.1016/j.ijrmms.2007.09.013*

Van Heerden, W.L., (1987). General relations between static and dynamic moduli of rocks. *Int. J. Rock Mech. Min. Sci. Geomech., Abstr. 24, 381–385*.

Yavuz, H., Tüfekçi, K., Kayacan, R., & Cevizci, H., (2012). Predicting the Dynamic Compressive Strength of Carbonate Rocks from Quasi-Static Properties. *Experimental Mechanics, 53:367–376 DOI 10.1007/s11340-012-9648-7*

Yap, R.F., Sepulude, J.L. & Jauregui, R., (1982). Determination of the Bond work index using an ordinary laboratory batch ball mill; designing and installation of comminution circuits. *Soc. Min. Eng., AIME, New York, 176–203.*