Energy Consumption Analysis in Marble Cutting Processing

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Abstract: Energy consumption is main cost part in marble cutting processing with circular sawblades. There exist many parameters that effect the energy consumption. It is possible to ensure optimization in the consumed energy if effects of such parameters can be fully understood. In this study, the effects of travel speed and saw rotation speed on energy consumption for two different natural stones. Cutting tests are realized with the computer controlled test set. In tests, while travel and saw rotation speeds are selected in different values, the cutting depth and cooling water is kept fixed. The results obtained for two cut stones indicate that travel and saw rotation speeds have significant effects on the consumed energy and the effect of travel speed is greater than the effect of saw rotation speed.

Introduction

Marble is a material widely used in many fields from past to today with its different natural colors and patterns. Afyonkarahisar is one the most important marble supplier cities of the world and Turkey with its plenty of marble mines and factories. In Afyonkarahisar, also the sectors that manufacture marble treating machines and their spare parts have developed together with the marble industry. Today, if we wholly consider the industry in Afyonkarahisar region, the share of marble industry in total industry is about 50%. Most of the production costs in marble treating consist of the consumed electric energy. By using the energy in optimum level, the costs can be decreased.

Various machines are being used for marble treating at mines and factories. For separating the block marbles taken from mine to plaques, block cutting machines segmented diamond circular sawblades are used. The name of such machines kwon as S/T in short originates from Striper and Trimmer words. There exist many parameters effecting the cutting operation in cutting machines segmented diamond circular sawblades. These parameters are saw rotation speed, travel speed and direction, cutting depth, mineralogical and physico-mechanic features of marble, metallurgic and mechanic features of diamond sockets on saw, flowing speed of cooling water and saw thickness. Many studies have been realized to examine the effects of the said parameters [1-12]. Studies generally focus on the effects of cutting situation (Buyuksagis 2007, Buyuksagis and Goktan 2005, Xu et al. 2004 and Li and Malkin 2001), cutting parameters (Tutmez et al. 2007, Ersoy and Atıcı 2004, Xu et al. 2003 and Xu et al. 2002) (cutting speed, travel speed, cutting depth) and saw structure on cutting performance and efficiency (Ersoy et al. 2005, Sun et al. 2002, Chen 2000 and Chen et al. 1999).

Studies made until today generally have focused on saw quality, abrasion and marble physiology. Today, as decrease in energy consumption is very important, studies on determination of electric energy consumed in marble cutting and optimization of consumption are required (Chuang 2005, Kleimaier and Schröder 2004 and Martynenko and Siregar 2002). In this article, the effects of travel and saw rotation speeds on energy consumption is examined. In this paper, the effect of parameters on specific cutting energy is researched and improvements that can be made are discussed.

Test set

Test sets having computer based data acquisition system are being used especially in scientific studies to make complex tests easily and transfer the results to a computer medium in a secure manner (Hazarika et al. 2006, Zoric and Ilic 2005 and Caldara et al. 1998). In this study, a completely computer controlled test set in prototype of S/T machine is used (Figure 1). Control of test set from computer is realized with an interface prepared with Delphi program language (Figure 2).

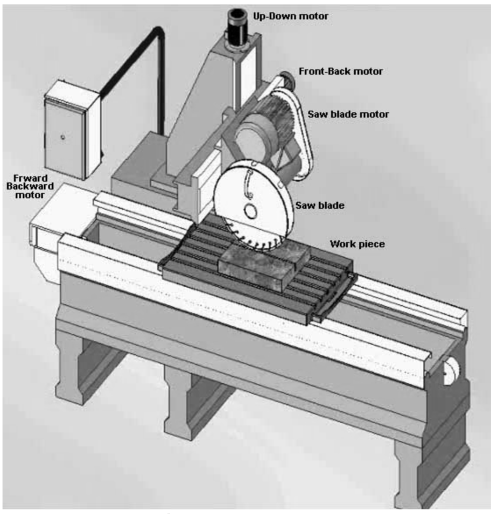


Figure 1. Test set

In this test set, travel speed, saw rotation speed, cutting depth and flow speed of cooling water can be adjusted very sensitively on computer. Saw rotation speed, travel speed and flow speed of cooling water can be changed uninterruptedly in intervals of 4000rpm, 0-4m/min. and 0-20l/min. respectively through there invertors driving the saw, travel and cooling water pump motors. Besides, vertical and horizontal positioning of saw can be made in millimeter sensitivity (Çimen et al. 2008).

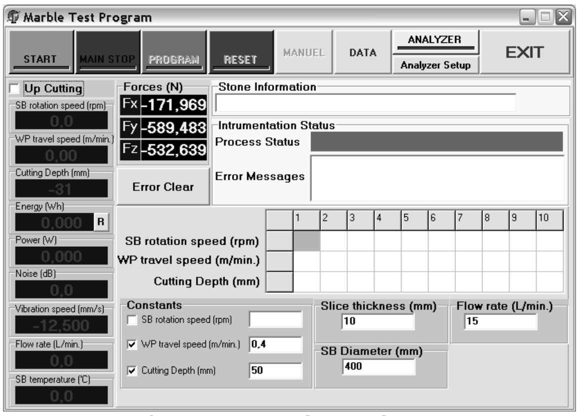


Figure 2. Interface software

As most of the energy in cutting operation is being used from vertical saw part, the energy consumption measurement and analysis can only be realized for saw motor (Çınar 2007). For measurements, Shark 100 energy analyzer is used. Analyzer, by digitizing the currents and voltages of three phase with analog-digital converter (ADC) with 16 bit resolution and six synchronous system , calculates and transfers the active, reactive and apparent power values drawn by the motor, harmonic distortions in current and voltage and consumed energy values to computer via serial terminal (Çınar 2007).

During the test, data such as current, voltage, power values and saw rotation speed are collected by the interface program. Data collected by the interface program are recorded in a text file in order to be treated in spreadsheet program later.

Tests and Analysis

Cutting operation is realized with movement of work piece towards to fixed saw. When the movement directions of saw and work piece given in Figure 3 is considered, down-cutting position is valid. During the cutting process, water is flowed to sawblade in order to cooling of sawblade and removing of sawdust. All cutting tests in this study are realized in the below cutting position.

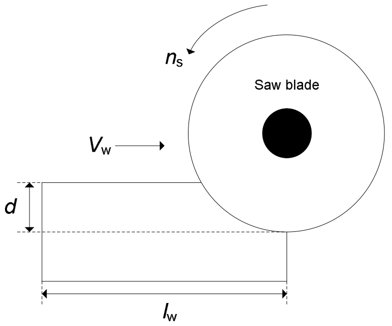


Figure 3. Cutting mechanism

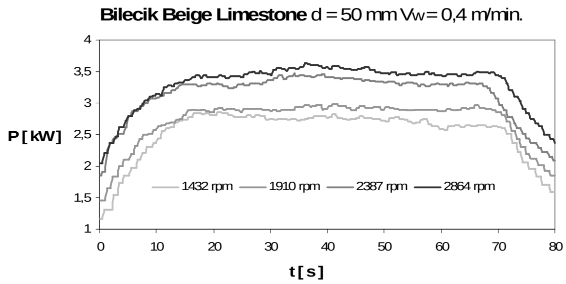


Figure 4. Cutting test power curve

The data record commences when the work piece touches to the saw and continues until the contact of saw axis with the work piece ceases. In Figure 4, active power graphics obtained from a group of tests made for different saw rotation speeds are given. As it can be seen, active power demand of motor rises starting from idle working value and when the saw axis enters into the work piece completely, it remains almost fixed. The power demand decreases towards the end of test and with leaving of the saw axis from the work piece, it falls again to idle working value. Though the travel speed and saw rotation speed are kept fixed at their adjusted values, there may changes in power values. The reason of this the change in hardness of marble during the cutting process as the marble is not a homogenous material.

The energy account is made depending on the active power values obtained from the tests. The active energy is equal to area below the power curve. Total energy used can be determined with the 3.1 integral (Çınar 2007).

$$E_{total} = \int_0^T p(t) \times dt \qquad (3.1)$$

Here, Etotal indicates cutting energy (Ws), p active power function (W) and T cutting time (s). Momentary energy values calculated by multiplying active power values by sampling time are continuously being added and so total cutting energy is obtained. This energy value is converted from Ws (Watt second) to kWh (kilowatt hour) unit in order to be more meaningful.

For specific cutting energy calculation defined as energy consumed per unit volume, the 3.2 formula is used (Çınar 2007).

$$SE = \frac{w_{total}}{q_w} \qquad (3.2)$$

Here, SE indicates specific cutting energy (kWh/m3), Etotal total cutting energy (kWh) and qw total volume of channel opened by the saw (m3). In Figure 5, channels opened by the saw on the work piece are seen.

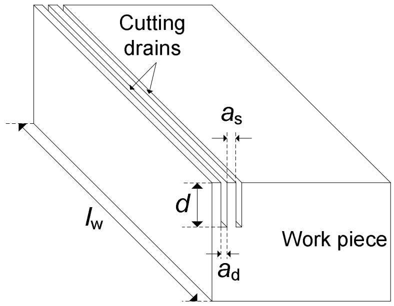


Figure 5. Work piece and cutting channels

$$q_w = a_d \cdot d \cdot l_w \quad (3.3)$$

Channel volume (qw) is calculated with the 3.3 formula. Here, lw indicates the length of work piece, d cutting depth and ad channel width.

Test results and discussion

In this article, two types of natural stones Bilecik beige marble and Denizli travertine are used for cutting tests. The selected two rocks have almost adverse features with respect to their physical and mechanical structures. While Bilecik beige marble has a very hard and small particle dimension, Denizli travertine has very soft and big particle dimension.

In the study, total 20 variation tests are made for each rock to observe the effect of travel speed and saw rotation speed. Tests are realized for (Vw) 0.3, 0.4, 0.5, 0.6 and 0.7m/min values of travel speed and (ns) 1432, 1910, 2384 and 2864rpm values of saw rotation speed.

Besides, in all cutting tests, the cutting dept and flow speed of cooling water are fixed in d=50mm value and in fw=12l/min. value. In Table 1, the specific cutting energy values obtained for each variation are given in groups. The data summarized in the Table are discussed below under separate headings.

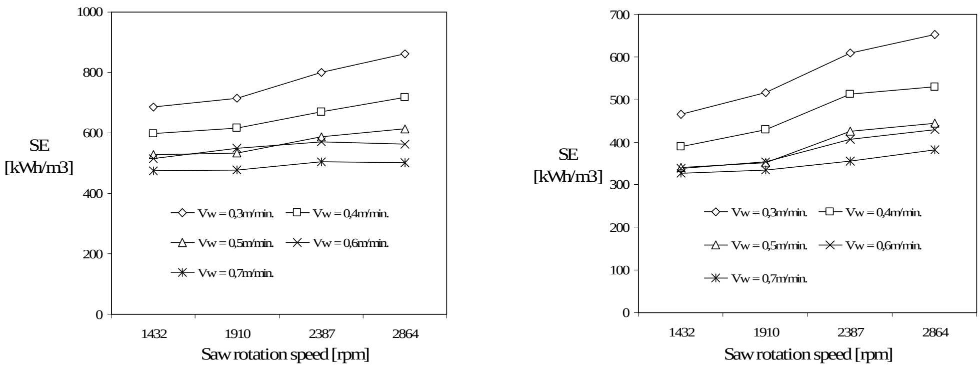
V_w [m/min]	n_s [rpm]	Denizli travertine SE [kWh/m^3]	Bilecik beige marble SE [kWh/m^3]
0.3	1432	464,51	685,37
	1910	516,51	713,34
	2384	609,28	800,32
	2864	652,12	861,71
0.4	1432	390,21	597,48
	1910	428,58	615,43
	2384	513,37	668,55
	2864	529,19	717,80
0.5	1432	340,35	528,88
	1910	352,43	534,59
	2384	425,21	585,96
	2864	445,14	613,68
0.6	1432	339,22	514,59
	1910	353,83	549,77
	2384	406,67	570,11
	2864	430,31	562,82

0.7	1432	327,03	475,27
	1910	334,68	478,40
	2384	356,47	505,19
	2864	381,22	502,01

Table 1. Specific cutting energy values for variation values

Effect of saw rotation speed on specific cutting energy

With increase of saw rotation speed, specific cutting energy also increases. For each rock examined in the study, specific cutting energy demonstrates a marked increase especially in low travel speeds (0.3 and 0.4 m/min.) (Figure 6). Increase in saw rotation speed (provided that travel speed will remain fixed) will cause more energy consumption unnecessarily as well as it will speed deformation of sockets. For this reason, saw rotation speed must be kept in a value most convenient for the cut marble.

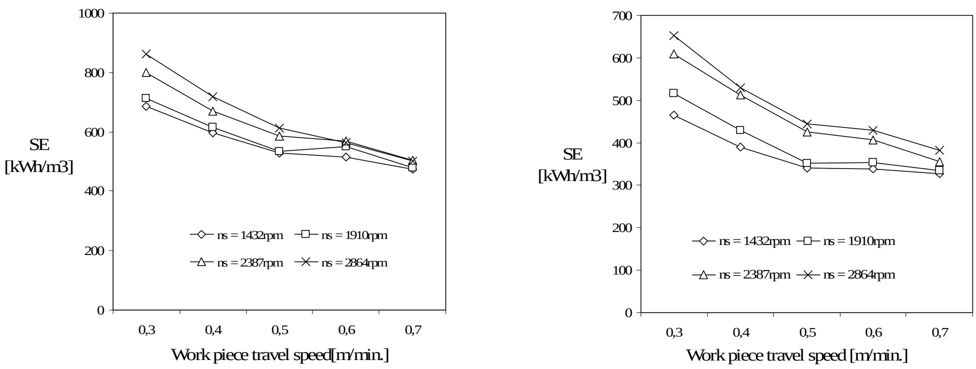


(a) (b)

Figure 6. Effect of saw rotation speed on specific cutting energy for Bilecik beige marble (a) and Denizli travertine (b)

Effect of travel speed on specific cutting energy

According to the analysis made for Bilecik beige marble and Denizli travertine, increase in travel speed decreases the specific cutting energy. While increase in travel speed increases the active power demand, it causes decrease in cutting time. Decrease in cutting time naturally decreases the specific cutting energy. On the other hand, for all saw speeds (1432, 1910, 2385 and 2864rpm), values of specific cutting energy come very close to each other after some definite value of travel speed (Figure 7). The said becoming closer point in graphics can be defined as region where the travel speed value gets its optimum value.



(a) (b)

Figure 7. Effect of travel speed on specific cutting energy for Bilecik beige marble (a) and Denizli travertine (b)

When the graphics showing the effect of saw rotation and travel speeds on specific cutting energy are examined together, it can be seen that the effect of travel speed on specific cutting energy is greater than the saw rotation speed. This is very clear from incline of graphic curves. For this reason, adjustment of travel speed rather than speed of saw rotation will be more economical and easy approach.

Results

In this study realized with a completely computer controlled block cutting machine, the effects of travel and saw rotation speeds on active energy and specific cutting energy are examined on two natural stones. In this study, the following results are obtained;

- With increase in travel speed, the specific cutting energy decreases. To increase the travel speed results with decrease in cutting time and so increase in cutting efficiency.
- To increase the saw rotation speed results with increase in specific cutting energy. As increase in saw rotation speed (provided that travel speed shall be kept fixed) will also increase the active power demand of motor, this means consuming more energy for the same work.
- The travel and saw rotation speeds have significant effects on cutting energy. With determination of optimum values of travel and saw rotation speeds, it is clear that the energy will be able to be used in productive manner. Even a saving in rate of 10% in energy consumption will bring significant benefit for Afyonkarahisar of which half of industry is established on marble treating.
- With studies to be carried out in future on the prototype test set used in that study, travel speed controllers ensuring optimum energy consumption (like PI, PD, PID and Fuzzy) will be developed. Such controllers will be able to keep the travel speed in its optimum value by monitoring the energy consumption of motor during cutting. Besides, in case the expected performance from the developed controllers can be obtained, it will be also applied on S/T machines used in the industry.

References

Buyuksagis IS, 2007, “Effect of cutting mode on the sawability of granites using segmented circular diamond sawblade”, Journal of Materials Processing Technology, Elsevier Transactions on, March, Vol.183, pp 399-406.

Buyuksagis IS and Goktan RM, 2005, “Investigation of marble machining performance using an instrumented block-cutter”, Journal of Materials Processing Technology, Elsevier Transactions on, Nov., Vol.169, pp.258-262.C.

Caldara S, Nuccio S and Spataro C, 1998, “A virtual instrument for measurement of flicker**”,** Instrumentation and Measurement, IEEE Transactions on, Volume 47, Oct. pp. 1155 – 1158.

Chuang HJ, 2005, “Optimisation of inverter placement for mass rapid transit systems by immune algorithm”, IEE Proceedings of Electric Power Applications, Jan., Vol.152, pp.61-71.

Chen W, 2000, “Cutting forces and surface finish when machining medium hardness steel using CBN tools”, International Journal of Machine Tools & Manufacture, Now., Vol.40, pp. 455-466.

Chen H, Li J, Spence J and Li JCM, 1999, “An ELID-cutting saw”, Journal of Materials Processing Technology, Feb., Vol.102, pp.208-214.

Çınar SM, 2007, Optimization of Electric Energy Consumption in Marble Cutting Machines, Dissertation Thesis at Afyon Kocatepe University, Electrical Education Department.

Çimen H, Çınar SM and Nartkaya M, “The Development of Software and Hardware for Marble Cutting Tests”, 2nd WSEAS Int. Conf on COMPUTER ENGINEERING and APPLICATIONS (CEA’08) Acapulco,Mexico, Volume 1, 25-27 Jan. 2008, pp. 244 – 249.

Ersoy A, Buyuksagis I S and Atıcı U, 2005, “Wear characteristics of circular diamond saws in the cutting of different hard abrasive rocks”, Wear, Elsevier Transactions on, Nov., Vol.258, pp 1422-1436.

Ersoy A and Atıcı U, 2004, “Performance characteristics of circular diamond saws in cutting different types of rocks”, Diamond and Related Materials, Elsevier Transactions on, Jan., Vol.13, pp 22-37.

Hazarika D, Laskar S Sarma A and Sarmah P K, 2006, “PC-Based Instrumentation System for the Detection of Moisture Content of Tea Leaves at Its Final Stage”, Instrumentation and Measurement, IEEE Transactions on, Volume 55, Oct. pp. 1641 – 1647.

Kleimaier A and Schröder D, 2004, “Optimization Strategy for Design and Control of a Hybrid Vehicle”, IEEE Proceedings of 6th International Workshop on Advanced Motion Control, Nagoya-Japan, Dec.8-10, Vol.2, pp.1084- 1089.

Martynenko YG and Siregar HP, 2002, “Optimization of power consumption of anthropomorphic robots driven by electromotor”, Proceedings of the Third International Workshop on Robot Motion and Control, Ponzan, Nov.9-11, pp.113-117.

Polini W and Turchetta S, 2004, “Force and specific energy in stone cutting by diamond mill”, International Journal of Machine Tools and Manufacture, Sept., Vol.44, pp.1189-1196.

Sun L, Pun J and Lin C, 2002, “A new approach to improve the performance of diamond sawblades“, Materials Letters, Elsevier Transactions on, Dec., Vol.57, pp 1010-1014A.

Tutmez B, Kahraman S andGunaydin O, 2007, “Multifactorial fuzzy approach to the sawability classification of building stones”, Construction and Building Materials, Elsevier Transactions on, Sep., Vol.21, pp 1672-1679W.

Xu X P, Li Y. and Yu Y, 2003, “Force ratio in the circular sawing of granites with a diamond segmented blade”, Journal of Materials Processing Technology, Aug, Vol.139, pp.281-285.

Xu X P, Li Y, Zeng WY and Li LB, 2002, “Quantitative analysis of the loads acting on the abrasive grits in the diamond sawing of granites”, Journal of Materials Processing Technology, Oct., Vol.129, pp.50-55.

Xu XP, Li Y and Malkin S, 2001, “Forces and Energy in Circular Sawing and Grinding of Granite”, Journal of Manufacturing Science and Engineering, Feb., Vol.123, pp.13-22.

Zoric AC and Ilic SS, 2005, “PC-Based System for Electrocardiography and Data Acquisition**”,** 7th International Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Services, Serbia and Montenegro-Nis Volume 2, 28-30 Sept. pp. 619 – 622.