Performance of New Innovative Cutting Machines in Dolomitic Marble Mining

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ABSTRACT

Diamond wire saw technique is most commonly used in marble quarrying. New innovative cutting machines i.e. variable speed diamond wire saw machine and single diamond wire block dressing machine, have been tried to improve cutting efficiency as well as to reduce waste reduction in marble mining. Research work is undergoing in dolomitic marble mines at Morwad (Distt: Rajsamand, Rajasthan) of M/s R.K. Marble. The performance so far achieved is encouraging in regards to application of these machines. The life of diamond beads as well as cutting speed have been increased gradually. This paper highlights the results of the experimental work carried out at the quarry site.

Keywords: Dolomitic marble**,** diamond wire**,** peripheral speed, thrust, cutting speed.

1. INTRODUCTION

Marble reserves in India are estimated at 1200 million tonnes with Rajasthan accounting for 91% of the reserves i.e. 1100 million tonnes available in 15 districts (Lal and Singh, 2000). Out of these, the main reserves are of dolomitic marble in Rajsamand district of Rajasthan. For economic exploitation of marble deposits, systematic and scientific mining is the critical need of the time and for this selection of proper equipment and innovative technology is required.

The basic principle of stone cutting with diamond wire saw technique is the rubbing (abrasive action) of diamond beads on stone through properly made diamond wire fed by the pulley arrangement mounted with gear box on the wire saw machine. The variable speed diamond wire cutting machines and single diamond wire block dressing machine have been introduced systematically for the first time in dolomitic marble at Morwad mines of R.K. Marble of Rajsamand district of Rajasthan in the month of July, 2005. Presently, all the "Wire saw machines" deployed at quarry site in Rajasthan are operating at fixed peripheral speed i.e. 27. m/s. The peripheral speed of the wire can be varied from 14 to 30 m/s in variable speed machine and 0 to 30 m/s in block dressing machine to increase the life of the diamond beads and to reduce the water consumption.

The performance of innovative cutting machine depends on the peripheral speed of the diamond wire, quantity of cooling media i.e. water, dolomitic marble properties i.e. soft, medium hard & hard etc. The peripheral speed of the variable diamond saw wire machine is being kept low i.e. 20 m/s at initial & final stage of bench cut and during the cutting of corners, which increases the beads life. The initial speed of the block dressing being kept low (to increase the life of diamond beads on the cutting top surface (or profile) of the block) is generally uneven.

Water is very important input for cutting the marble blocks and it has to be optimized based on temperature of beads and slurry (marble cutting) position on diamond wire during cutting to avoid the abrasive action between base wire and sleeve of the diamond beads. An energy meter has been installed to determine the power consumption per cut of the marble block. The performance of these machines is measured in the form of cutting speed (sq.m. /hr) and beads life, and compared with the performance of fixed speed machine.

2. DESCRIPTION OF STUDY AREA

The study area Morwad mines of R.K. Marble (P) Limited is situated near village Morwad, at a distance of 15 km in western direction from district headquarter Rajsamand (Rajasthan). The area has moderate hills of Aravalli region.

Marble belt of Morwad area belongs to the Raialo series. The Morwad area exhibits a huge concentration of dolomitic marble. This marble is highly crystalline containing coarse grained blades of tremolite and actionolite. The marble formation also contains a number of amphibolites intrusive veins. The marble formations are surrounded by "Banded Gneissic Complex" rocks. These are medium grained, pinkish & grayish coloured and nonporphyritic rocks. The marble deposit of this area is well foliated in nature containing knots of quartz and feldspar. Biotite gneisses present in marble also show a similar deformation pattern. The bands in the gneiss are marked by dark streaks and rich in ferromagnesian mineral mainly biotite and alternating with light colored quartz feldspar layers.

3. FIELD INVESTIGATIONS

3.1 Variable Speed Diamond Wire Saw Machine

This machine (Fig. 1) is manufactured by Marini Quarries Group, Italy. It is equipped with a main 50 HP (440V/50Hz) A.C. electric motor and with an inverter which allows to vary the linear peripheral wire speed from 14 to 30 m/sec through potentiometer. The speed of diamond wire is controlled by a special electronic device which gets feed back from the cutting load/stress, while cutting the marble bench. This keeps a constant tension in diamond wire and stops the machine in case of malfunctions or wire breakage. An auxiliary motor controls a quick machine movement on rails for positioning. The 360^0 rotation of main flywheel (dia. 820 mm) is motorized. The lateral movement is controlled mechanically.

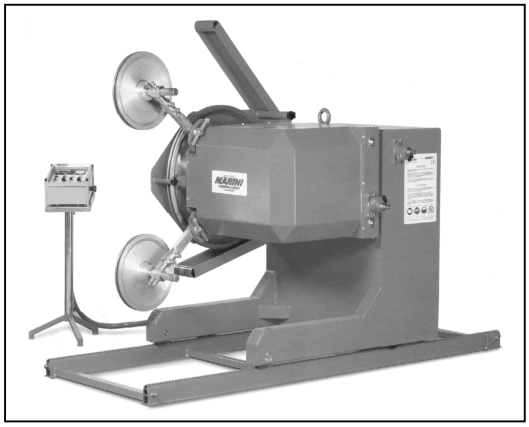


Fig.1 - Variable speed diamond wire saw machine

Fig.2 – Vertical cut with diamond wire saw (variable speed) at Pit no. 40 in medium dolomitic

Fig. 3 - Diamond wire with 2000 number of beads

The diamond wire of variable speed diamond wire machine consists of 2000 beads and locking of beads is done after every three beads. Wire uses steel washers and small springs (12 mm length) and is shown in Figure 3. The cutting rate (m^2/hr) has been

measured in hard, medium and soft dolomite marble, keeping diamond wire speed of 27 m/s in general and 20 m/s at initial and final stage of cut and at corners of the bench.

The feed rate was kept constant for maintaining the ampere of main motor between 55-60 amps. The cutting parameters like peripheral speed, thrust (load on wire) and water quantity have been kept same as for the fixed speed machine. The details of the observation are given in Table 1.

Table 1 - Details of bench cuts in dolomitic marble with variable speed diamond wire saw machine

Cut No.	Type of Dolomitic marble /Pit no.	Type of cut	Schimdt rebound hardness (MPa)	Size of cut L x H (m)	Cut area (m^2)	Duration of cut (hrs)	Bead temp (^0C)	Cutting rate m^2/hr
1	Med./31II	VS	40	4.88 x 8.38	40.90	9.0	29	4.54
2	Med./31II	VS	40	4.72 x 8.38	39.59	9.66	29	4.10
3	Med./31II	VS	40	7.16 x 8.68	62.19	14.66	29	4.24
4	Med./31II	VS	40	6.25 x 8.63	53.34	9.50	29	5.62
5	Soft/22	V	34	13.87 x 9.91	137.39	27.08	28	5.07
6	Soft/22	V	34	14.48 x 9.75	141.23	26.33	28	5.36
7	Hard/43	V	45	16.76 x 7.32	122.60	33.33	30	3.68
8	Soft/12	V	35	15.39 x 7.62	117.27	22.75	29	5.15
9	Soft/12	V	35	15.54 x 7.62	118.45	21.83	29	5.43
10	Soft/4	V	32	15.54 x 10.21	158.68	27.08	28	5.86
11	Soft/4	V	32	16.91 x 10.05	170.08	26.16	28	6.50
12	Soft/20	V	34	17.2 x 10.97	188.73	38.83	28	4.86
13	Soft20	V	34	16.92 x 10.97	185.66	33.25	28	5.58
14	Soft/4	V	32	14.02 x 10.24	143.58	31.25	28	4.59
15	Hard/40	V	42	21.18 x 8.84	187.21	46.16	30	4.05
16	Hard/39	V	44	9.75 x 8.99	87.66	28.00	30	3.13
17	Hard/39	V	44	9.91 x 9.14	90.62	24.08	30	3.76

Notations: Med. – Medium; VS – Vertical strand cut (Machine at top of the bench); V-Vertical cut (Machine at the bottom of the bench)

3.2 Single-Diamond Wire Block Dressing Machine

This machine is manufactured by Wires Engineering, Italy. It is a single diamond wire machine for block dressing at quarry and processing plants (Fig. 4). This machine is suitable to cut marble, granite and any kind of stone. The strong structure of the machine is made by two steel columns connected by a steel beam and two aluminum flywheels of diameter 1000 mm slide on each column. The ascent and decent movement of the flywheels is controlled by a trapezoidal rod system driven by 1.5 Kw electric motor. The diamond wire tension system is driven by a pneumatic device (1.5 Kw - 9 bar) that works on the two upper flywheels and it is controlled all through the cutting phases. The 15 Kw main A.C. motor (440 Kw Volt – 50 Hz) is connected to the right lower flywheel. It is also equipped with a water distributor system to cool the diamond wire and to clean the cut.

Fig. 4 - Single diamond wire block machine and cut surface of the block

The study so far being carried out is with plastic coated diamond wire supplied along with this machine. During study the penetration rate of diamond wire is being kept at 53 cm/hr for 20-30 mm or after taking in account the top cut surface profile of the block. The downward feed rate was kept at 120 cm/h and water quantity 4.5 litre/min. The study was undertaken for different diamond wire peripheral speed 27, 28, 29 & 30 m/s. The details of cuts made for dressing of the blocks are given in Table 2.

3.3 Study for Water Optimization

The water is very precious commodity in this part of country and it has to be optimized for block dressing operation. A study was made by reducing the water quantity from 6 litre/min to 1 meter/litre and the bead temperature was measured on block 5 of Pit no.33, and slurry deposition on beads & wire has been noted (Table 3).

4. ANALYSIS OF THE DATA

4.1 Performance Analysis of Variable Speed Diamond Wire Saw Machine

The primary mode of diamond tool wear in sawing is diamond breakdown due to impact and fatigue, with the secondary mode being tool wear through abrasion of the matrix. With impregnated tools, continuous, efficient cutting can only be facilitated by compatible wear of the diamond particles and their bonding matrix (Wright et al., 2000).

Table 2 - The details of the cuts made for dressing of the blocks

Date	Type of Dolomitic marble/ Schimdt rebound hardness	Size of Block W , H (m)	Cut area (m^2)	Diamond wire peripheral speed (m/s)	Time for cut (hrs)	Cutting rate (m^2/hr)	Avg. Amp. during cutting (amp)	Bead Temp (^{0}C)	Energy Kwh/ sq.m.
13.8.05	Soft/ 36	1.75, 0.91	1.60	28	1.08	1.48	11.2	29	3.81
---do--	Soft/ 36	1.60, 1.67	2.68	28	1.33	2.02	11.8	29	3.12
--do --	Soft/ 37	2.67, 1.60	4.27	28	1.5	2.85	12.8	30	3.02
14.8.05	Soft/ 37	1.98, 1.37	2.71	29	1.42	1.91	12.5	31	4.13
---do--	Soft/ 36	2.51, 1.37	3.44	29	1.16	2.96	13.8	30	3.80
15.8.05	Soft/ 17	3.35,1.37	4.59	29	1.66	2.76	15.8	31	3.07
---do--	Soft/8	1.7, 1.09	1.86	29	1.16	1.60	9.5	30	3.27
16.8.05	Soft/ 23	1.92, 1.49	2.86	29	1.66	1.72	11.5	30	3.42
--do--	Soft/ 23	2.44, 1.40	3.42	29	1.33	2.57	13.5	30	2.63
----d0--	Hard/ 27	2.07, 1.58	3.28	29	1.33	2.46	12.2	31	3.07
---do--	Soft/ 39	2.31, 1.31	3.02	29	1.33	2.27	12.8	30	2.98
---do --	Soft/ 39	2.22, 1.31	2.90	29	1.33	2.19	12.5	30	3.10
17.8.05	Soft/ 20	2.31, 1.31	3.02	29	1.33	2.27	13.8	30	3.14
--do--	Soft/ 20	3.05, 1.71	5.20	29	1.66	3.14	14.8	30	2.59

Table 3 - Study details for water optimization

S.No.	Size of Block W x H (m)	Cut area ($m^{2)}$	Water Quantity (l/min)	Duration of cut (minutes)	Bead temp (^{0}C)	Remark
1	2.08 x 1.71	3.55	6	30	27	No sluury on beads & wire
2			4.5	30	28	No slurry on beads & wire
3			3	30	29	Slurry have been seen on beads & wire
4			2	30	31	Slurry have been seen on beads & wire
5			1	30	35	Dry powder seen with slurry

The harder rock gives more wear of the wire and lower cut productivity (Stellin et al., 2004). Stellin et al. (2004) further noticed that the productivity decreases as the quartz percentage in the rock increases.

The performance analysis of variable speed diamond wire saw machine was carried out on the same parameter of peripheral speed and thrust as it was in fixed speed machine. The results were obtained on all three category of dolomitic marble i.e. soft, medium and hard. As the hardness of rock is increasing, the cutting rate is decreasing (Fig. 5). The temperature of beads measured during cutting with infrared thermometer, was increasing as the hardness was increasing (Table 3).

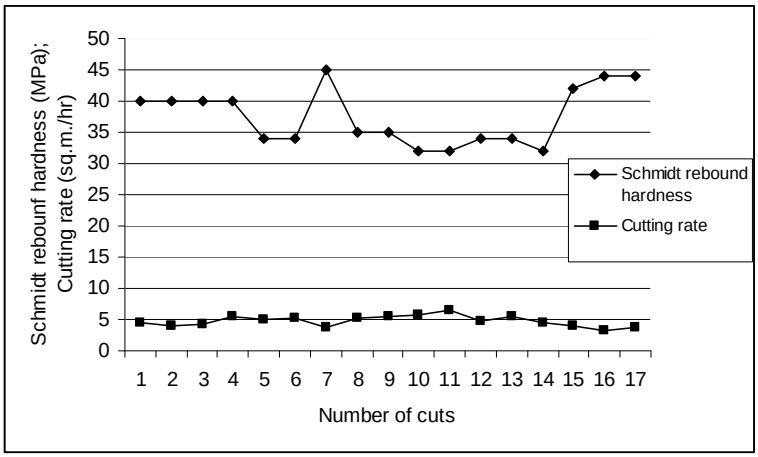


Fig. 5 - Relation between Schmidt hardness and cutting rate

Figure 6 shows the performance curve of optima make diamond wire during its life. The trend of regression line represents downward trend of cutting speed. It is because the diamond beads get conical shape in the front part. The cutting force applied along the axis of the bead and the resistance of the rock to the progression of the cutting diamonds at the rock bead contact raises the momentum arises, which must be compensated by an increase of the bead pressure at the front part of the bead rock contact with respect to the rear part (Mancini et al., 2001). The cutting speeds of optima make diamond wire shows increasing trend as the cutting area increases (Fig. 7). The number of diamond beads increases in contact with rock during cutting as the area increases.

The average cutting speed with variable speed machine in soft and medium hard dolomitic marble shows increasing trend in comparison to fixed speed machine (Table 4). In hard strata the cutting speed depicts downward trend. The average life of diamond wire with variable speed machine was increased in comparison to fixed speed machine. It was due to the low speed i.e. 20 m/s kept at the start and end of bench cutting and while cutting of corners.

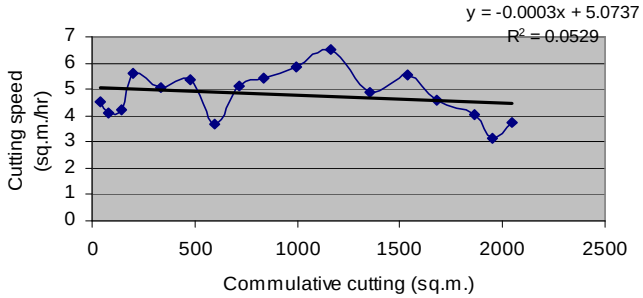


Fig. 6 – Performance curve of diamond wire with variable speed machine

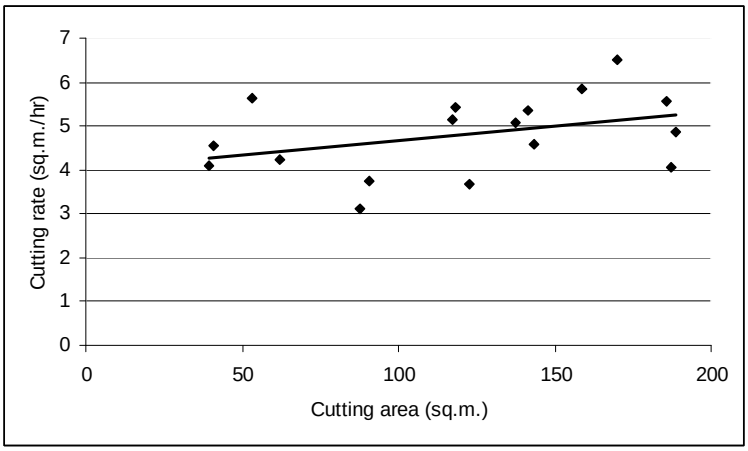


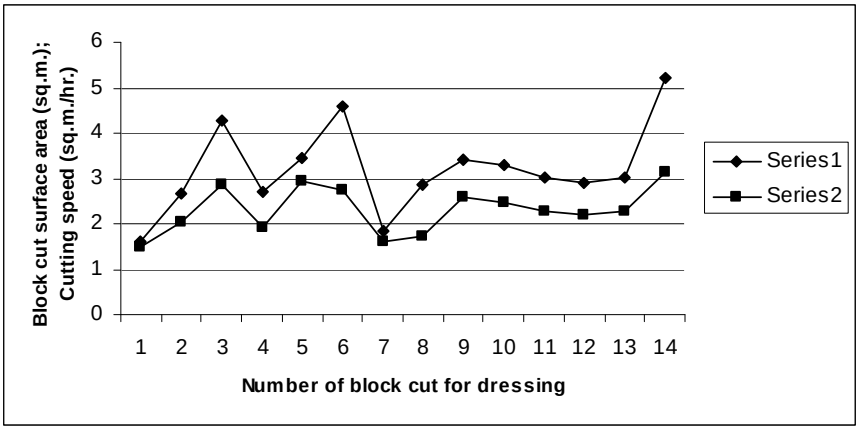
Fig. 7 - Relation between cutting area and cutting rate

Table 4 - Comparison of cutting speed with variable speed machine and fixed speed machine (Peripheral speed 27 m/s and Thrust 55-60 amp.)

Type of dolomitic rock	Average cutting speed with Variable speed m/c (sq.m/hr)	Average cutting speed with fixed speed m/c (sq.m/hr)
Soft	60	55
Medium Hard	52	43
Hard	38	41

4.2 Performance Analysis of Single Diamond Wire Block Dressing Machine

This machine was introduced for first time in the dolomitic quarry of M/s R.K. Marble for finishing the blocks produced in the mines. The data recorded in Table 2 depicts that the cutting rate increases as the cut area of the blocks increases (Fig. 8). The reason is that the more diamond wire length was in contact with stone. The Fig. 9 shows that the energy consumption in Kwh/sq.m. decreases as the cut area of the block increases. The temperature of beads increases as the peripheral speed and area of cut surface increase. The energy consumption also increases as the hardness of the dolomitic marble increases**.**



Note**:** Series-1 for surface area; Series -2 for cutting speed

Fig. 8 - Cut surface area and cutting speed

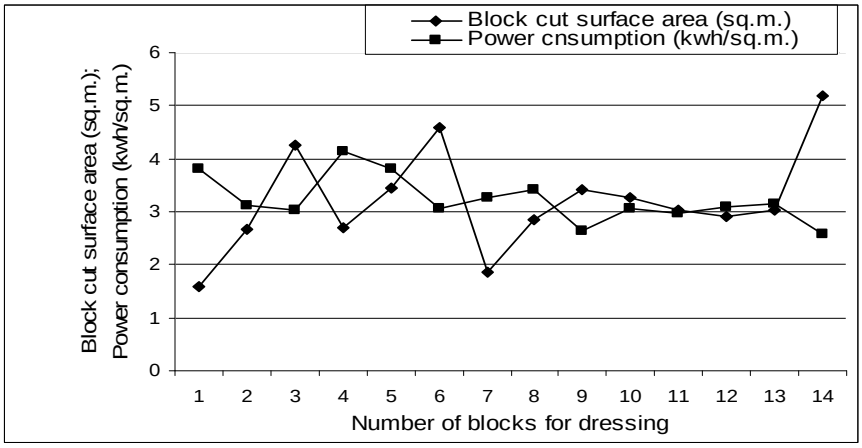
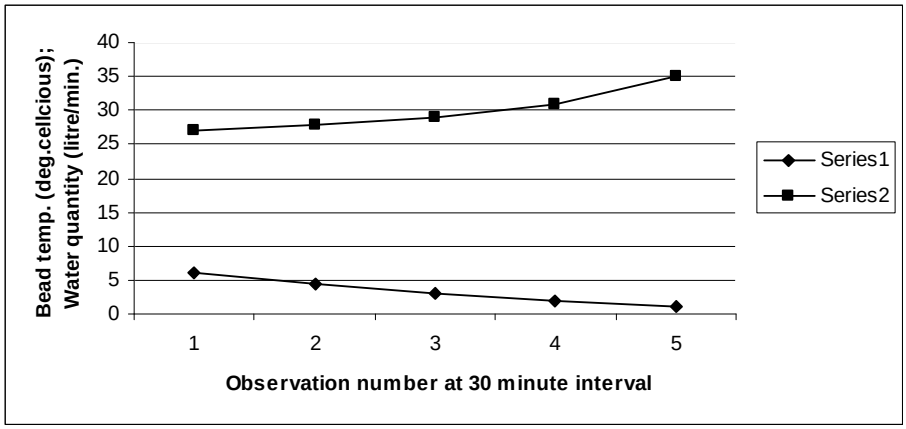


Fig. 9 - Block cut surface area and power consumption

To optimize the water quantity, the bead temperature was measured at different water quantity levels i.e. 6, 4.5, 3, 2 & 1 litre/min. The bead temperature has been given in Table 3 (Fig. 10). As water quantity reduces, the temperature of beads increases, as expected. The slurry was seen accumulated on beads and wire at 3, 2 & 1 liter/min water quantity. Hence, 4.5 liter/min quantity is appropriate for removal of slurry produced during cutting.

4.3 Cost Comparison for Block Dressing by Different Methods

The cost comparison for dressing of single block (size 2.4 m x 1.67 m) with single-diamond wire block dressing machine and by jack hammer drilling (two machine) using diesel operated compressor, was carried out and summarized in Table 5.



Note**:** Series-1 for water quantity; Series -2 for bead temp

Fig. 10 - Relation between water quantity used for dressing of cut and diamond bead temp

Table 5 - Operating cost comparison for block dressing (only power consumption)

Parameters	Single-diamond wire block dressing	Jack hammer drilling (two machine) using diesel operated compressor
Size of block	2.4 m x 1.67 m	2.4 m x 1.67 m
Time in dressing (hrs.)	1.45 hrs (Feed rate 1.15m/hr) The time required for loading and setting was not considered	2.21 hrs (Drilling rate of one jack hammer is 9m/hr and total drilling required was 40m for 24 holes)
Power consumption	12.5 units	28.8 litre diesel consumption
Operating cost	Rs. 57. 75	Rs. 950
Value addition to block	Rs 2000-3000 Have finished surface, 20 mm thickness of block is saved, and also saving in transportation and dressing cost (avoiding of block dressing at factory site).	-

Table 5 shows that the dressing time was more in conventional dressing of blocks by jack hammer drilling. The operating cost was very high in dressing with jack hammer drilling. Beside this with diamond wire block dressing machine, one gets finished surface of block after dressing which gives value addition to block significantly.

5. CONCLUSIONS

- The life of diamond wire was increased in soft and medium hard dolomitic marble by using variable speed diamond wire machine.
- Water quantity was optimized on the basis of diamond bead temperature and the slurry deposition on diamond wire. It was 4.5 liter /min. for block dressing to get an optimum output.
- The cutting rate increases as the cut area of the block increases.
- As the hardness of dolomitic marble increases, the diamond bead temperature also increases, as expected.
- The energy consumption in Kwh/sq.m. decreases as the cut area of the block increases.
- The operating cost reduces significantly with the use of block dressing machine as compared to jack hammer drilling method. The value addition to blocks was also observed additionally.

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