

Cutting Performance of Chain Saws in Quarries and Laboratory

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ABSTRACT: Preliminary results of a project supported by TUBITAK (The Scientific and Technological Research Council of Turkey) are presented in this paper. Turkey's natural stone industry is firstly summarized. The field performance of a Garrone chain saw used in Basaranlar Marble and Travertine Co located in Denizli-Turkey is summarized. Wear of the cutting tools/bits are analyzed and classified. Tool wear rates are summarized.

The study sets the first step of the research project. Although it is not presented in this paper, as a future work, travertine block samples are obtained for performing a set of full-scale laboratory linear rock cutting tests using chain saw cutting tools to deterministically simulate the chain cutting

1 INTRODUCTION

Chain saw machines are used for cutting low abrasive soft to medium strength natural stones with such as travertine and marble, in both underground and surface quarries. They can perform both vertical and horizontal cuts and usually used together with diamond wire cutting machines. Using chain saws for dimensional stone production increases the overall performance of the quarries by providing for higher quality product, reducing production losses to enter a new face and time losses for horizontal borehole drilling and wire placement.

Machine manufacturers usually manufacture standard models. The miners use these standard machines for cutting every type of natural stones. However, it is very well known in rock cutting mechanics that as the rock properties change, the optimum cutting conditions change, as well. Therefore, the design of lacing pattern of the cutters should be modified for different stones and cutting conditions for improved cutting performance. Any improvement of cutting rates of these machines, cutting harder stones and/or longer jib lengths would also increase the competition power of both miners and machine manufacturers. In this context, analysis of chain saw performance is an important subject.

Literature on performance of chain saws was rather limited in the past. Mellor (1976) analyzed kinematically the working principles and design parameters of continuous belt machines such as coal cutters, trenchers, chain saws. Mancini et al (1992, 1994) analyzed the parameters affecting the performance of different chain saws, and simulated geostatistically the chain cutting, the results were compared with the field performances of different chain saws working in different conditions. Mancini et al (2001) analyzed in-situ the chain saw applications in terms of cutting performance, tool wear and stone parameters affecting these issues.

Chain saw performance depends on geological conditions of the quarry, chain saw (mechanical) features/specifications, and operational parameters. Geological parameters include rock mass properties such as joint set number and frequency, dip and direction of the deposit, and intact rock properties such as uniaxial compressive strength, tensile strength, elastic properties, texture and petrographic properties. Mechanical parameters include torque-power-thrust capacities, jib (boom) length, lacing design of the cutting tools and cutting tool properties. Operational parameters include jib cutting angle, chain rotation speed, and water feeding when cutting, cutting vertical or horizontal, jib cutting angle, quality of labor, material availability, etc.

2 NATURAL STONE INDUSTRY OF TURKEY

Natural stone utilization rate started rapidly increasing especially after the World War II and still continuing to increase. This acceleration became more clear after 1980s in Turkey. The main reason for this improvement was that natural stones were included in the Mining Law of 3123 instead of the previous Quarry Law, which had very strict rules for the natural stone producers. Additionally, the improvements in the world was closely monitored in that period and miners started using diamond wire cutting machines, (Yuzer, 2005).

Turkey has totally 7.6 billion tons of natural stone reserves (proven and probable) in different colors, textures and types such as crystalline calcareous stones, limestone, travertine, conglomerate, breccia, sandstone, granite, siyenite, diabase, serpentine, etc. Turkey's natural stone reserves take about 33% share of world reserves. Reserve improvement works are on the way.

Share of Turkey in world stone production is about 8%, taking usually the rank between 5 and 10 in the world. In 2003, the world natural stone production was about 75 million tons, 6 million tons of which were coming from Turkey. The slab production capacity of Turkey is about 13 million m². While the production trend in the world show linear increase, it is exponential in Turkey. All of the stone production comes from private sector with more than 750 quarries (surface) and 1000 processing plants, employing totally around 60000 workers, (TCM, 2005).

Almost 60% of mining exports of Turkey comes from natural stone industry and travertine takes more than 50% share of the natural stone exports. About 4% of the world natural stone trade belongs to Turkey, taking usually the 5th rank. Turkey's yearly natural stone export values are presented in Figure 1.

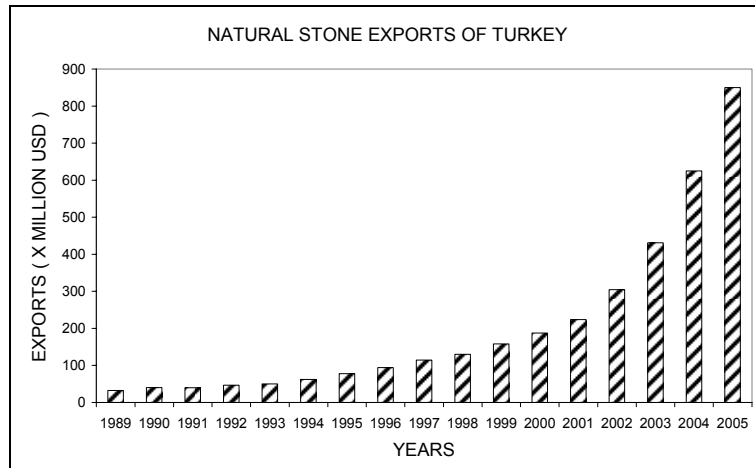


Figure 1. Natural Stone Exports of Turkey (Yuzer, 2005; TCM, 2006)

3 INTRODUCTION OF THE BASARANLAR TRAVERTINE QUARRY

One of the quarries of Basaranlar Marble Co is visited to analyze and measure the field performance of the chain saw, which is the only one in that quarry. Basaranlar Marble and Travertine Co is located in Denizli, Figure 2. 90% of total production is carried out with marble and travertine from company-owned quarries. In the factory, mostly travertine and beige marble, also colored marble and limestone are processed. Company produces slabs, tiles, mosaics, borders, risers and treads, floorings and skirting, windowsills and columns, and other products depending on demand. Surface processing types include polishing, honing, patinato, tumbled, sand blasting, acid surface, rustic and edge chamfering. Slab production capacity is 180000 m²/year, tiles and sized slab production capacity is 540000 m²/year, and

antiquated and tumbled stones and mosaics production capacity is 120000 m²/year, being 840000 m²/year total annual production capacity. Yearly block production capacity is around 40000 m³, of which almost 20000 m³ is travertine. The factory has 9000 m² of closed area and 26000 m² of open area. Basaranlar Marble exports 80% of overall production to over 40 countries and the rest 20% is utilized in Turkey.

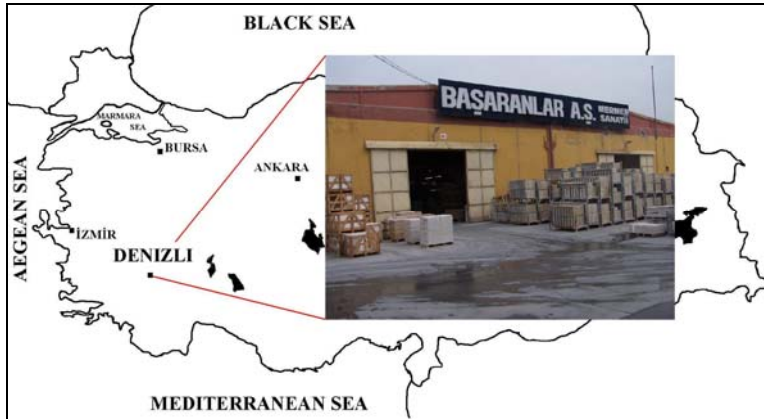


Figure 2. Location of the Basaranlar Travertine Quarry

Denizli Travertine Quarry of Basaranlar, which is visited for performance measurements of the chain saw used in the company, is located in Denizli/Kaklik in Ballik region. This region has one of the biggest travertine reserves of the world with many quarries. Light, medium and dark "Classic Travertine" productions are carried out in the region.

20000 to 24000 m³/year of travertine blocks are produced in Basaranlar Travertine Quarry, Figure 3. There is only one joint set in the quarry with 8 to 15 m of joint frequency. The deposit is only slightly dipping. The bottom horizontal surface is firstly cut by Garrone MCRH 340 chain saw. The cutting depth (jib reach) is around 3.2 m and cutting length is currently around 13 m. Vertical side and back surfaces with the height of 8 to 8.5 m are then cut by diamond wire cutting machines with 50-60 kW power after drilling vertical boreholes of 4 inch diameter in 6 to 7 m spacing. The blocks are then cut into smaller sizes of (2 to 10 m³) average 4 m³ in the quarry by diamond wire cutting machines with 20-25 kW. Around 35 personnel work in one of 8-hour-shift/day (in winter), two of 8-hour-shift/day (in summer) and 7 days/week.



Figure 3. A View of the Travertine Quarry

In the past, only diamond wire cutting machines were used in the quarry to produce travertine. After starting to use MCRH 340 to cut the bottom horizontal surfaces of the blocks, the overall performance of the quarry was improved about 20%. The basic reasons for that were using chain saw provided for higher quality product with smoother surfaces, reducing production losses to enter a new face and time losses for horizontal borehole drilling and wire placement into the boreholes.

4 FIELD PERFORMANCE OF GARRONE MCRH 340 CHAIN SAW

The machine used in the travertine quarry has been in use since May 2003. The machine achieved well since then, by improving the overall performance of the quarry about 20%. Therefore, Basaranlar Co bought another Garrone chain saw for their beige marble quarry located in Burdur. The technical features and a picture of the machine are presented in Table 1 and Figure 4, respectively.

Table 1. Technical Specifications of Garrone MCRH 340 Chain Saw (Garrone Catalogues)

| | |
|-----------------------|----------------|
| Weight | 6 tons |
| Electric Voltage | 380 V |
| Total Installed Power | 50 kW |
| Maximum Reach | 340 cm |
| Chain Speed | 0 to 1.8 m/s |
| Feed Motion Speed | 0 to 20 cm/min |
| Cutting Width | 42 mm |
| Oil Tank Capacity | 220 liters |
| Chain Pressure | 350 bar |
| Load Pump Pressure | 25 bar |
| Cart Move Pump | 50 bar |
| Arm Rotation Pressure | 70 bar |
| Jib Rotation | 360° |

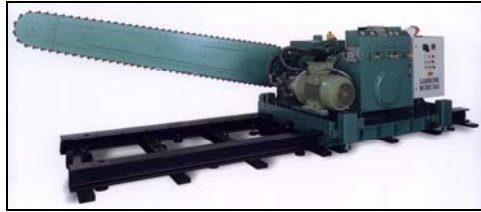


Figure 4. The machine used in the Travertine Quarry (Garrone Product Catalogues)

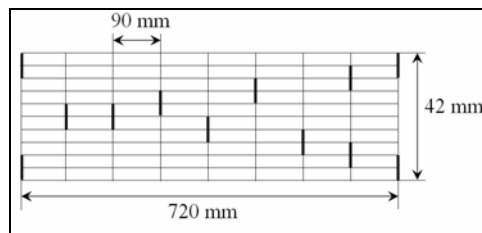


Figure 5. Tool Lacing

The tools are mounted on the sockets with 0° of rake angle and 8° of back clearance angle. Tool width is 12.7 mm with a hole of 5.1 mm diameter to screw it to the socket. Tool thickness is 6 mm. 8 Sockets (8 meshes with 90 mm distance), with total 10 cutting tools, make a cutting sequence of 720 mm length. Each of the sockets 1, 2, 3, 4, 5S and 5D includes 1 cutting toll and each of the last two sockets (6 and 7) includes 2 cutting tools. Thus, a cutting sequence includes 10 tools. Total socket number is 98 (8.82 m of chain length), resulting in 12.25 sequences in total. The tool lacing design is presented in Figure 5.

The machine is basically used for cutting the bottom horizontal surfaces of the blocks. The rails are placed 130 cm from the vertical wall. Currently applied cut length is around 13 m. Water flushing is mostly applied for improving the muck discharge out of the cut slit and cooling the cutting tools. The cutting performance of the machine for a year of period starting from May 2003 to April 2004 are summarized in Table 2, based on the records of the quarry personnel.

The performance observations and records by the authors indicate that when there is no free surface to enter a new cut face, the machine sumping in the corner takes around 65 minutes for total sumping length of 2.25 m and jib reach of 3.2 m (total 7.2 m²). This means that the net cutting performance of the machine for sumping is 6.646 m²/h. However, the rest of the cutting job for 10.5 m cut length (33.6 m²) is achieved in 175 min, resulting in the net cutting rate of 11.507 m²/h. In total 12.75 m of cut length, average net cutting rate is 10.2 m²/h. Around 8 liters per second water flushing is applied during cutting. Chain speed, cart movement pressure, chain rotation pressure and average dept of cut for a single tool when cutting 10.5 m section is 1.2 m/s, 15 bar, 100 bar and 0.6 mm, respectively. And also, the jib (boom) cutting angle is around 15 degrees.

Table 2. Cutting performance and cutter wear rate of Garrone 340 chain saw (records of the quarry personnel)

| PERIOD | AVERAGE LENGTH OF EACH CUT (m) | CUT SURFACE AREA (m ²) | CUTTING TIME (h) | NET CUTTING RATE (m ² /h) |
|---------------------------------|--------------------------------|------------------------------------|------------------|--------------------------------------|
| May 2003 | 26.4 | 1436.8 | 138.2 | 10.397 |
| June 2003 | 18.1 | 1329.6 | 127.0 | 10.469 |
| July 2003 | 20.4 | 1801.8 | 158.0 | 11.404 |
| August 2003 | 13.4 | 1098.0 | 107.5 | 10.214 |
| September 2003 | 25.0 | 1040.0 | 106.0 | 9.811 |
| October 2003 | 24.9 | 1910.4 | 150.0 | 12.736 |
| November 2003 | 31.0 | 694.4 | 58.0 | 11.972 |
| December 2003 | 20.4 | 1046.4 | 112.0 | 9.343 |
| January 2004 | 16.3 | 470.4 | 58.0 | 8.110 |
| February 2004 | 25.6 | 982.4 | 122.0 | 8.052 |
| March 2004 | 17.0 | 1193.6 | 164.0 | 7.278 |
| April 2004 | 17.7 | 1529.6 | 206.0 | 7.425 |
| AVERAGE | | | | 9.768 ± 1.783 |
| TOTAL NUMBER OF TOOLS CHANGED = | | | 1870 | tools |
| TOTAL CUT AREA = | | | 14533.4 | m ² |
| TOOL WEAR RATE = | | | 0.129 | tools/m ² |

The observations indicate that the sumping action in a corner reduces the performance in the 10.5 m section from 11.506 to 10.2 m²/h (around 11%). Therefore, it is important to keep the bench lengths and cutting length as longer as possible to get higher performances.

Four edges of the tools are utilized before tool change. After an edge is worn, all the cutters are switched together to the next cutting edge. Tool change takes around 1 hour with one personnel.

A batch of worn cutters is also analyzed visually in this study. Four general groups of wear type are defined: major breakage (around half of the tool is broken and lost), minor breakage (small pieces of tool is broken and lost), major abrasive wear (half width and the corners of the tool is worn) and minor abrasive wear (only the corners of the tool is worn), Figure 6.



Figure 6. Major and Minor Breakage of the Tools

5 CONCLUSIONS AND FUTURE WORK

Adding only one chain saw to the equipment fleet (diamond wire cutting machines) of the Basaranlar Travertine Quarry improves the overall performance of the quarry about 20%. The basic reasons for that is using chain saw provided for higher quality product with smoother surfaces, reducing production losses to enter a new face and time losses for horizontal borehole drilling and wire placement into the boreholes.

The results of performance observations and records indicate that if there is no free surface when starting the cutting operation, the machine should perform a sumping action, which reduces the overall performance of the machine by around 10% for 13 m of cutting length. Therefore, it is useful to keep the total bench lengths and cutting lengths as long as possible. The cutting tool wear rates are around 0.129 tool/m² in the quarry. Wear types are classified into 4 general groups: major breakdowns, minor breakdowns, major abrasive wear, and minor abrasive wear.

The study sets the first step of the research project. Although it is not presented in this paper, as a future work, travertine block samples and cuttings from the chain saw cuts are obtained for performing a set of full-scale laboratory linear rock cutting tests using chain saw cutting tools to deterministically simulate the chain cutting action and some physical and mechanical property tests in the laboratories of Mining Engineering Department, Istanbul Technical University. The full-scale laboratory linear rock cutting tests result in tool forces and specific energy to cut a unit volume of rock, and optimum cutting configuration and tool lacing are defined for a certain stone type by reducing torque and thrust requirement of the machine, thus increasing machine performance.

6 REFERENCES

- Mancini, R., Cardu, M., Fornaro, M. and Toma, C.M., 2001c, "The Current Status of Marble Chain Cutting." Proc. Mine Planning and Equipment Selection, pp. 151-158
- Mancini, R., Cardu, M., Fornaro, M., Linares, M. and Peila, D., 1992, "Analysis and simulation of stoen cutting with microtools." Proc. III Geoengineering Congress, Rock Excavation: The Future and Beyond, 1-2 Dec., Torino, Italy, pp. 227-236
- Mancini, R., Linares, M., Cardu, M., Fornaro, M. and Bobbio, M., 1994, "Simulation of the operation of a rock chain cutter on statistical models of inhomogenous rocks." Proc. Mine Planning and Equipment Selection, Eds. Pasamehmetoglu et al., pp. 461-468
- Mellor, M., 1976, "Mechanics of cutting and boring, Part 3: Kinematics of continuous belt machines." CRREL (US Army, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire), Special Report, #76-17
- TCM, Turkish Chamber of Mines, 2005, "Natural Stone and Marble report." <http://www.maden.org.tr/yeni3/yayinlar/raporlar/mermerraporu.htm>, in Turkish
- Yuzer, E., 2005, "Development of Turkish Natural Stone Industry." Stone 2005, Yapı Endüstri Merkezi, in Turkish

7 ACKNOWLEDGEMENTS

TUBITAK (The Scientific and Technological Research Council of Turkey) is appreciated for their support on the Project 105M017. The authors would also like to thank to Adnan Saraçoğlu, President of SET Makine Ltd. Sti., for his valuable contributions and help on this study.