Study and Analysis of cutting forces in Granite Machining

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***Abstract*-In this paper the measurement of cutting forces in conventional tools are reviewed and the prototype band saw machine is monitored. Cutting forces in this new process are studied, with measurement of tangential force and feed force under various working conditions. And also compare the advantages of band saw machine over the conventional tools used in granite processing.**

Keywords - Stone sawing, diamond tools, cutting thickness, band saw, cutting force.

I. INTRODUCTION

The study of cutting forces in granite processing is a field that has developed only recently.

Segment cutting can be considered as abrasion at multiple contact points (diamond grains) at different passing depths, Only a few grains of diamond form part of the abrasion process on each pass. A variety of factors influence this process, such as diamond grain concentration in the matrix, grain geometry, each diamond grain's protrusion out of the matrix, and so on.

The diamond segment is made up of sintered diamond grains in a matrix. As the diamond is stronger, it remains in view and the supporting matrix is eroded away. Wear on the matrix varies according to the attack face or the tail face of the diamond grain,

The segment is at the top of the figure, and the rock at the bottom. The segment moves towards the right, which means the segment's attack face is also to the right. Greater wear on the matrix is observed at this attack face, which leads to some protrusion of the diamond out of the matrix, and less wear takes place on the tail side as the matrix material is protected by the diamond grain. When good protrusion of the diamond out of the matrix is produced, the segment is said to be sharp as it is this protrusion that does the actual cutting.

Estimating and discovering the exact cutting forces in ornamental rock sawing is a difficult task as it depends on many factors such as the specific strength of the rock being cut, the cooling water flow rate, the type of segment fitted, how worn this is, and so on.

2. FORCES IN CUTTING PROCESS

2.1 Diamond wire cutting

We used a conventional 8 mm diameter diamond wire for cutting at an axial speed of 23 m/s. The cutting of Red granite was studied with 110 MPa of compressive strength. Feed force was measured, but not the force in a tangential direction from the cut. Graphs were produced with the above force values for different stone widths and feed speeds, Figure 1:

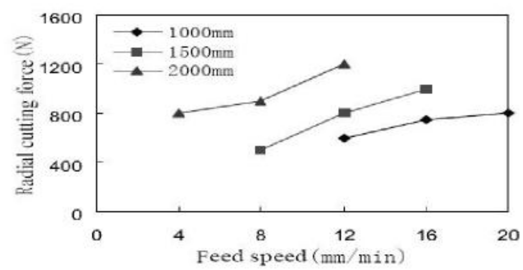

Figure 1. Forces in diamond wire cutting,

With the amount of material removed unchanged, it is not the same to cut a wide material with a slow feed as it is to cut a narrow material with a fast feed. The narrow material needs a faster feed, which means the effective area of each working diamond grain is greater, that is, there is a greater feed per grain of diamond. For the wider material the feed per grain of diamond is less for the same amount of material removed.

There has also been study into the influence of cutting speed, although the cutting tool, a 0.8 mm diameter wire, was totally different. In the work by Ge, it was discovered that given a significant increase in cutting speed a slight reduction in tangential force was produced.

2.2 Circular blade cutting

The main parameters for diamond disc cutting are, Figure 1: cutting speed, v_s, is the tangential velocity of the disc at the moment of cutting; feed speed, v_w, is the velocity at which the disc's axle is moved relative to the rock; and pass depth, a p, is the depth at which the disc penetrates into the rock at each pass.

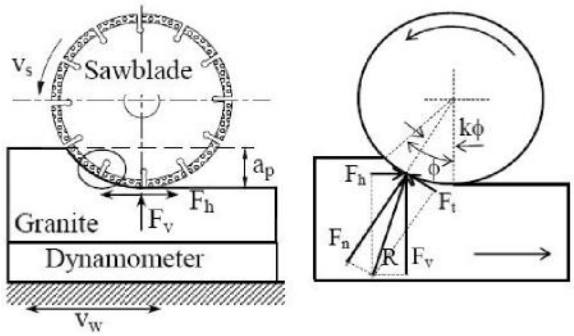

Figure 2. Force diagram for disc cutting,

Several studies provide normal, tangential, or compound cutting force.In the case of diamond disc cutting the amount of removed material per time unit is obtained as the product of the pass depth times the feed speed. Some articles, provide the normal and tangential force value, versus specific removal rate. See some results on the figure 3.

This tests were carried out on two granite types, grey and red, but their compressive strength was not given. According to documental research this could be between 110 – 180 MPa. The machine was fitted with a 350 mm diameter disc, with 3.6 mm wide segments, and cut at a speed of 30 m/s.

The efficiency of a given cutting process is measured by specific energy, which is defined as the energy consumed per unit volume of material removal. So, some tests deal with specific energy measurement and how it is influenced by feed rate, wear or cutting depth.

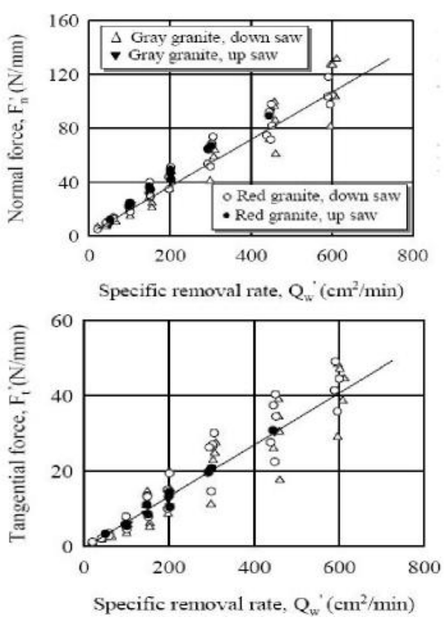

Figure 3. Cutting forces according to material removal rate

2.3 Frame cutting

Frame cutting is different from other cutting processes, there is an alternating strip movement and feeding is not done in a constant way. That is why cutting force calculations are more complicated and studies made are limited to giving average force values according to average feed values. What can be said from their data is that the force in the normal direction is between three and 3.5 times the value of the tangential force.

2.4 Band saw cutting

To measure granite rock cutting forces with band saws, a data acquisition system must be prepared for the prototype machine as nonesuch is available off the shelf. As in the first part, two rock types were cut during the tests: brown granite as a soft one, and pink granite as a hard one.

3. MONITORING THE SMALL MODEL MACHINE

The tangential cutting force (FT) and the normal feed force (FA) will be measured. Several instruments are used to measure force: monitoring of the electric motor operating parameters and a hydraulic system, but the base instrument for these measurements will be a linear guide system coupled to a force transducer, as can be seen in the following figure:

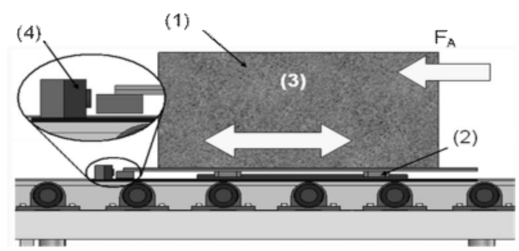

Figure 4. Block setup using linear guides for force measurement

The granite block (1) is placed between two plates with a linear guide system (2). Thus the rock (1) is easily moved in direction (3), and when cutting it, the force in the feed direction, FA, aligned with the guide system (2), is entirely transmitted to the force transducer (4). Furthermore, the linear guide system setup will also be valid for measuring the tangential force (FT) rotating 90º the guide lines, and aligning them with the tangential direction. To minimize errors due to friction, small rocks are used for measurement taking.

3.1 Tangential cutting force

Both from the data recorded from the motors and from the force transducer, it can be seen that the tangential cutting force remains highly uniform during cutting. The tangential cutting force hardly undergoes any change as the feed moves forwards, the oscillation that appears is no greater than 0.5 N and at times an oscillation of this value can be seen when cutting a length of rock with constant parameters.

Due to inaccuracies caused by friction in the guide system and influencing factors such as the concentration of diamond grains, specific state of wear, etc., it was decided to set limits for the maximum force value recorded.

Forces were measured, and the results will be showed per millimetre of thickness cut, in this case, 4 mm. Tangential force will be represented for a range of removed material amounts, Table 3, always with 25 m/s of cutting speed.

Table 1. FT for 500 mm wide rock

	Hard granite (Pink Porriño)	Soft granite (brown silvestre)
Material removed	0 – 5 0	0 – 5 0
Tangential force per mm	< 7.5	< 5

The tangential force value needed to make a cut is very similar, despite the different properties of the materials being cut. This could be due to the fact that the force in a tangential direction is caused to a greater extent by the drag of the detritus produced in the cut as well as the drag of the cooling water.

The tangential force needed to keep the machine moving has been estimated at 56 N, which means the tangential force to maintain the cut, under the measured conditions, has a really low value, below 50% of the force needed to keep the machine in operation. Such a small force has few mechanical design implications for the machine, but it can relevant with regards motor size as 65% of power deployed by the motor is used to keep the machine running rather than cutting.

3.2 Feed force

According to the tests carried out, the feed force is greater than the tangential cutting force, above all for hard granite. Just as before, forces were measured, and the results will be showed per millimetre of thickness cut, in this case 4 mm. Normal feed force will be represented for a range of removed material amounts, Table 4, always with 25 m/s of cutting speed.

Table 2. FA for 500 mm wide rock

	Hard granite (pink Porriño)		Soft granite (brown silvestre)	
Material removed (cm^2/min)	0 – 3 0	3 0 – 5 0	0 – 5 0	5 0 – 1 00
Feed force per mm (N/mm)	< 10	< 20	< 5	< 7 . 5

For the feed force, normal to the cut, the difference between the two materials is much more representative. For similar amounts of removed 2 material (up to 50 cm /min), the force for the pink granite, 20 N/mm, is found to be four times greater than that for the brown granite, 5 N/mm. According to the literature this difference is due to the hardness of the material, as a cutting force in the normal direction is what the diamond grain applies to the rock to be cut in order to compress it and gradually achieve the destruction of material.

This can also be clearly seen in the results, where the greater the amount of material removed, the greater the necessary feed force, which is even more obvious with the hard granite.

The tests were always done working with saws with 2 a useful section of 1.3x 38 mm and several tensions on the saw, but always with low values in order to obtain longer duration.

Keeping up a stress of 25 MPa on the saw, which meant 1,250 MPa of force per saw section, it has been shown empirically that with feed forces below 30 N (7.5 N/mm) the cut is kept straight. For a stress of 60 MPa, 2,960 N of force per stretch, it can be seen that with forces below 70 N (18 N/mm) the cut is kept quite straight. It should also be said that some cuts made at speeds ranging from 40 – 50 cm^2/min in pink granite showed irreversible warping in the cut after time.

If the saw were oversized and similar stresses used for cutting steel could be applied, 120 MPa or higher, higher feed speeds for pink granite cutting could certainly have been achieved.

4. CONCLUSIONS

Firstly, it has been shown to be possible to cut ornamental rock with a band saw with diamond segments. When constructing the saw it is important to have good alignment in the die cutting and welding, and not to thermally affect the saw. The systems for detritus cleaning, saw positioning and cutting feed worked adequately. Points for improvement are the use of greater stresses on the saw, and a larger sized one. The aim of both these is to obtain greater feed speeds and improve this cutting system's competitiveness.

Despite the limitations in the cutting force measuring systems, a series of conclusions can be obtained from the measurements made.

The feed force, normal to the cutting direction, varies noticeably with the amount of material removed per time unit. This variation is more marked in a hard rock such as the Porriño pink than in a relatively soft rock like the brown silvestre. Compared to other cutting systems, the feed force in the band saw cutting has an intermediate value between that for discs and wires, greater than disc cutting, and smaller than diamond wire cutting.

The tangential cutting force has a relatively small value and represents, in general terms, only 35% of the power consumed by the cutting motor, the rest of the power is needed to keep the pulleys and the saw moving. For very hard rocks such as pink Porriño, the tangential cutting force comes to a third of the feed force. This detail also coincides with results from other researchers in similar materials, but using conventional cutting procedures. For softer rocks, such as the brown granite, the feed force and the tangential cutting force have a similar module.

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