Performance analysis of pulsating water jet machining during disintegration of rocks by means of acoustic emission

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Abstract: Over the decades water jet cutting has been widely used for rock disintegration in mining operations and quarrying purposes. The impact of high pressure waterjet on hard material like rock,coal ruins the original structure of the material therefore low pressure water-jet come into the existence. In recent year pulsating water jet has been applied in numerous ways such as surface cleaning, exclusion of damaged material layers, preparation of surfaces, and disintegration of materials. It has also a great potential for application in hard rock breakage as conventional methods are cumbersome, not readily accessible and have economical limitations.The performanceof the jet increses significantly by the generation of pulses causing disintegration of material at a relatively lower energy and costs. This paper focuses on the study of the disintegration processes of marble and granite by pulsating water jet subjected to erosion via accoustic emission.The experiments are performed by using pulsating water jet with modulation frequency of 20.20 kHz. The MVT circular nozzle with an orifice diameter of 0.9 mm, standoff distance from the target material was 6 mm, traverse speed varied from 2-16 mm/s and pump pressure 60 MPa was used for water jetting .The topography of granites and marble on the cut depth and surface quality were investigated by the optical profile-meter. Moreover, dependable relations between some physical and mechanical properties of the rocks and the depth of cut were observed. The online monitoring of acoustic emission shows the change in the response to the pulse frequency at different time intervals.

Key Words: Pulsating Water-jet, Marble and Granite, Acoustic emission.

1.Introduction

Water jet offers wide range of solutions in rock cutting and have greatly been used for disintigration of rocks. Manipulation of large volume of water at low pressure as a tool can be done efficiently and effectively (Knill et al., 1968).
Over several decades granite is being actively used as a building material due to its exceptional properties like resistance to aesthetic properties and environmental effects (Zelenak et al.,2015). Though granite is compatible with the environmental conditions it has limited industrial application. Since 1960 rock breakage technology is using high pressure, low volume jet-gained popularity in scientific research and industrial applications and pulsed water-jet provided new direction for hard rock breakage (Karakurt et al., 2012). Some of the studies have been mainly concerned to the effect of the nozzle shape on the reduction in velocity caused by the passage of the jet through air the nozzle design has an important effect on the disintegration of the rock in addition this transverse speed of the jet is also plays vital role during disintegration.

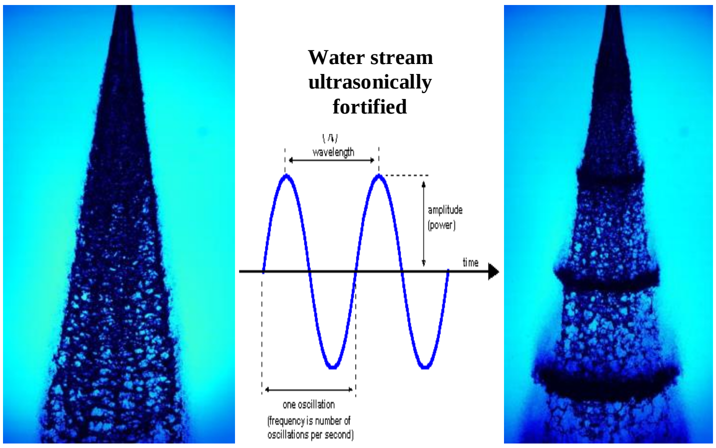

Fig:1.1 Water stream ultrasonically fortified on the left – without pulsation, on the right – with pulsation 20 kHz (Zelenak et al.,2015)

In the past two decades, the use of natural stone has been made more significant.The growing commercial market and competition for natural stone have resulted in increased demand for innovative manufacturing process (Tripathi et al., 2016). Due to the composition of natural stone (granite, shale, concrete) especially granite machining and processing with traditional system have some difficulties. Therefore new technology come in the picture that is pulsating water jet machining. Due to this increase machining efficiency by minimizing production time and cost required. Among the innovative manufacturing process water jet have developed broad application (J.L.Knill et al., 1968).

WJ has been widely used in exclution of damaged material layers, surface cleaning, breakage of biological material, and many other applications(Srivastava et al., 2016; Foldyna et al., 2012).The formation of pulses in pulsating water jet is based upon the generation of acoustic waves using a transducer which acts on the pressurized liquid and transmits it to the actuators in acoustic chamber filled with pressurized liquid. This acoustic waves are then amplified using a mechanical amplifier and transferred to the nozzle with the help of a liquid wave guide(Zelenak et. al., 2015; Lehocka et al.,2016).

The impact of the highly energized liquid mass stream on the solid surface causes the disintegration of the surface due to the formation of short pressure transients.

This phenomenon of disintegration consists of two main stages: a) Initailly the water hammer pressures are generated due to the compressive nature of the liquid. These pressures causes the most serious damages to the surface.b) As this impact pressure releases liquid starts flowing away fro the point of impact. The velocity with which the liquid flows tangentially is five times the impact velocity (Foldyna et. al.,2012).

Now a day's Acoustic emission phenomenon is one of the best phenomena. It is non-destructive testing of highly stressed material as a result of internal deformation mechanism may be used to examine the deformation and failure of rocks under load. In spite of this technique has been used in laboratory on the material such as gold crystal and wooden beams. It has been also found many applications in model studies of the earthquake and testing of the missiles casings.This method can be used in material research which are metal or nonmetal (Knill et al.,1968). The method and inspection of surface quality by continuous control (online) still remain the issue (Hloch et al.,2013; Delijaicov et al.,2010; Fowler et al., 2005; Hassan et al., 2004; Hloch et al., 2011; Safa et al., 2016). In accordance with the performed measurements we are searching for the dependence between acoustic emission and its factors of the WJ factor.

Hloch et al. (2013) investigated during the analysis of acoustic emission hydro abrasive cutting for indirect control that the behavior with the exactly scheduled change of the cutting condition and cutting head transverse and analysis and comparison of the examined section of the experimentation through FFT spectral analysis. They performed the experimental procedure on the single variable factor of the AWJ, to be analyzed the C sample monitored as solely i.e. the represent part of the large experiment. Application of the remaining sample A, B, D shows dependency on the variable factor changing speed, abrasive mass flow rate ma and focusing tube diameter d_f. These dependency or regulation equations are monitored through the online control process. Zelenak et al. (2015) investigated to visualize of the high-speed pulsating and continuous water-jet structures and velocity flow vector field to test the applicability of the shadowgraph technique combined with PIV processing algorithms.

The main aim of this work is to study the erosion effects caused during the disintegration of rock or mining material by pulsating water-jet. The acoustic emission was measured during the experimentation using the LABVIEW to describe the surface phenomena and studying the effects of parameters. In addition to this, the surface roughness of the obtained traces were evaluated using non-contact type optical profile-meter Microproof FTR and to determine the effects of parameters on the depth of cut.

2.Experimental Study

The experiment were conducted at Institute of Geonics of the CAS Ostrava Poruba.In order to study the disintegration processes of marble and granite by pulsating water jet via accoustic emission and vibration we used Software National Instruments (NI), LabView 2012 SP1 f5 ver. 12.0.1, Sound and Vibration Measurement Suite 12.0.0, Spectral Measurements Toolkit 2.6.3, Advanced Signal Procesing Toolkit 12.0.0 and hardware (NI) accelerometer WR712F-M4 up to 65 kHz. The technological setup includes: a) plunger pump Hammelmann HDP 253 b) Robot ABB IRB 6640-180 for handling the pulsating water head (Fig 2.1). Tab2.1 shows the experimental condition. An Ecoson WJ-UG_630- 40 generator was used as a source of acoustic waves for the generation of pulsating water jet .
The experiments were performed with the modulation frequency of 20.2 kHz.

Table 2.1: Experimental Condition

f [kHz]	*p* [MPa]	*d* [mm]	*z* [mm]	*v* [mm/s]	Material	A [mm]	P [W]	Liquid
20.2	60	0.9	30	2,4,6,8,10,12,14,16	marble	6	380	H_2O
20.2	60	0.9	30	2,4,6,8,10,12,14,16	granite	6	380	H_2O

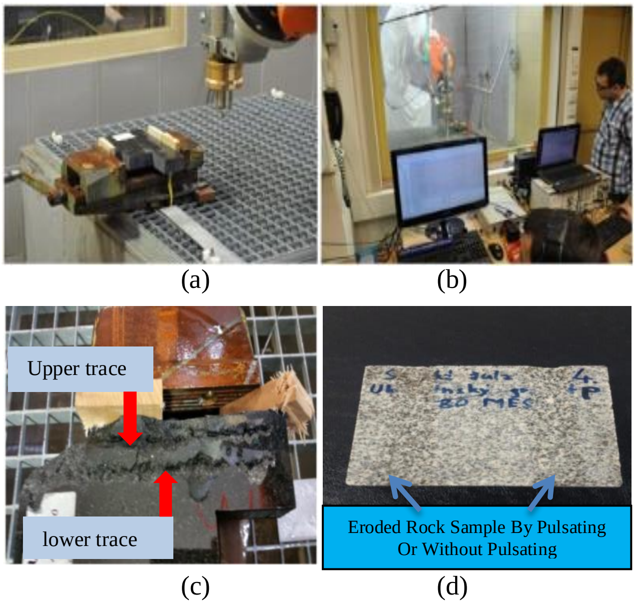

Fig: 2.2 (a)Experimental setup (b) Monitoring the process (c)rock sample with black granite(d) white marble

3.Result and Discussion

The surface roughness of the disintegrated samples of granite were measured using optical MicroProf FRT profilometer at the Institute of geonics AS CR, v.v.i. Ostrava. The 3D plots of the surface were evaluated for samples disintegrated under following conditions: Two cuts were performed by continuous water-jet using circular nozzle orifice diameter d = 0.9 mm at pressure levels p = 60MPa visible traces were observed only in case of PWJ.

Fig:3.1 shows the experimental setup of the optical profilometer with granite and marble samples. As it can be seen created grooves in 3-D and 2-D profiles which profiles represented the depth of cut and height during disintegration of rocks.

A high level of isotropy was observed from the parameter analysis of the disintegrated samples. From the topographical analysis of the surface of the grooves it was observed that a lower value of surface roughness Ra, Rq and Rz was achieved at v = 2 mm/s and v = 4mm/sec. In the fig. unevenly values of surface roughness was observed in form of peaks and and valleys. It was observed that as the feed rate was increased the values of the surface roughness were increased.

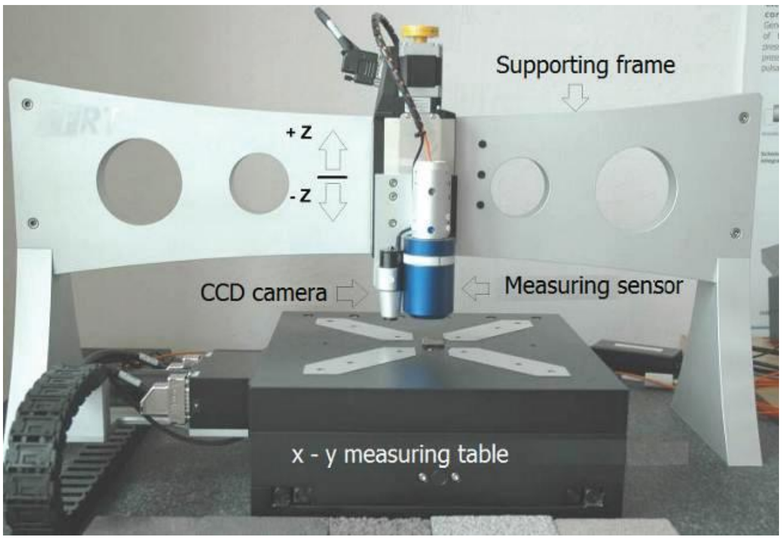

Fig:3.1 Non-Contact type Optical Profilometer

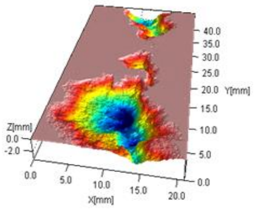

Fig:3.2(a) 3-D profile record during granite disintegration by pulsating water jet

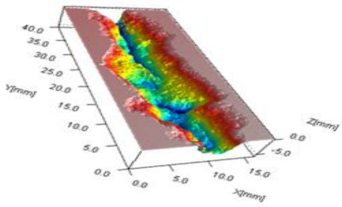

Fig:3.2(b) 3-D profile record during granite disintegration by continuous water jet

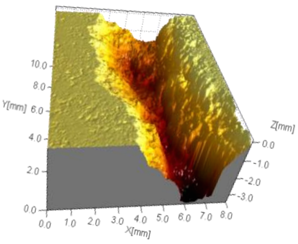

Fig:3.2(c) 3-D profile record during marble disintegration by pulsating water jet

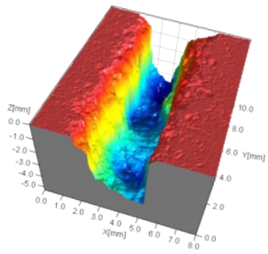

Fig:3.2(d) 3-D profile record during marble disintegration by continuous water jet

On comparing the traces of the pulsating and continuous water jet it was observed that the traces created by the pulsating water-jet were much deeper than continuous water jet. These depths generated by the flat nozzle during disintegration are shown in the fig:3.2(a)(b)(c)(d). Where the material is also squeezed out above the edge of groove the sample in case of the granite. Fig:3.2(c)(d) shows the maximum squeezed material on the transverse direction in which case they created higher grooves.

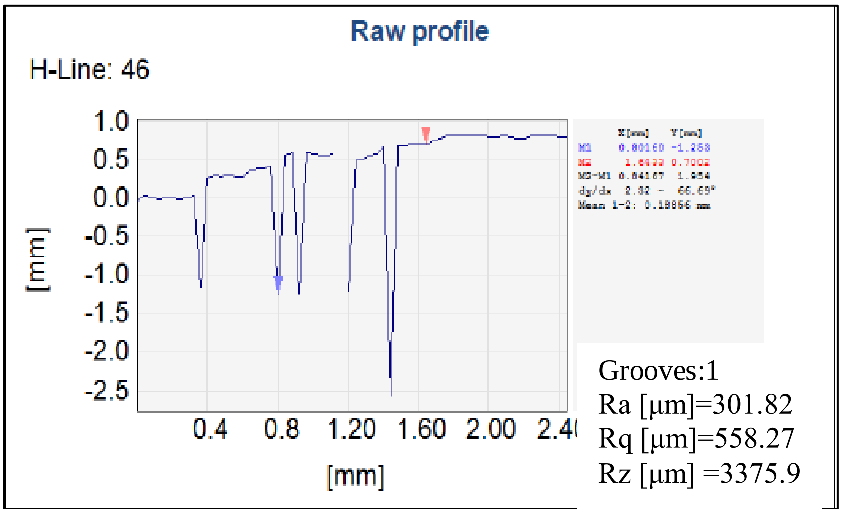

Fig.3.3(a): Graphical illustration of disintegrated grooves with pulsating water jet

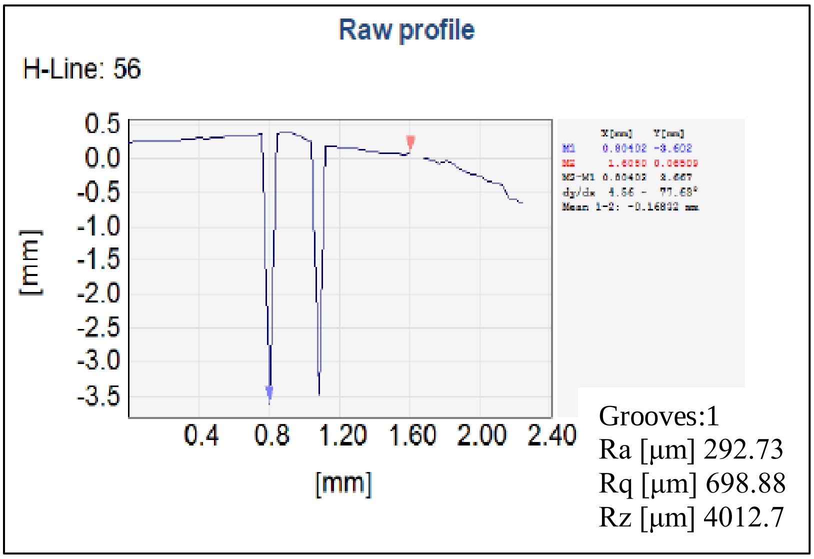

Fig.3.3(b) Graphical illustration of disintegrated grooves without pulsating water jet

It follows from the aforementioned case that a lower surface roughness can be achieved by the pulsating water jet with the higher transverse speed.

The figure below shows the frequency pulse vs time graph of marble and granite samples disintegrated by pulsating and continuous waterjet. From the experimental data the differnce during the time course of disintegration of granite by water jet and pulsating water jet by vibration can be seen in fig. 3.4,3.5 and 3.6. During the disintegration of rock by pulsating water jet the link between the material being cut and the optimum frequency of the pulse for different materials can show the change in the response to the pulse frequency.

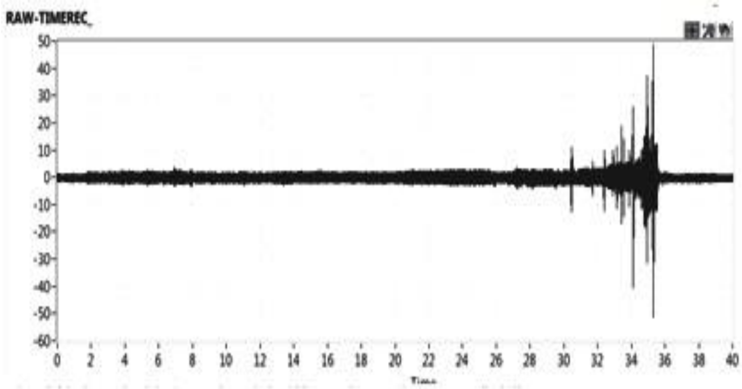

Fig.3.4 The time course of disintegration of marble by pulsating water jet by vibration.

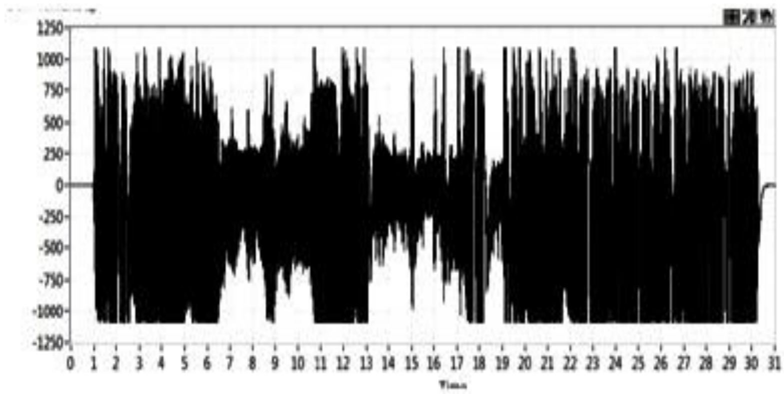

Fig.3.5 The time course of disintegration of granite by puslating water jet

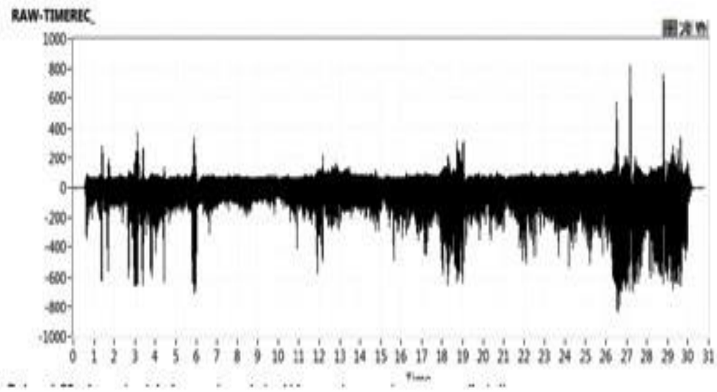

Fig.3.6 The time course of disintegration of granite by water jet .

The above graphs show that a more stable region was observed in case of samples treated with PWJ than continuous water jet.

4.Conclution and future scope:

This technology has been incresingly used in manufacturing field as well as the material is disintegrated by the shock impact waves [12], [13].The capacity of the pulsating waterjet in rocks was experimently investigated. The main conclution of the study can be summarized as follows:

- From the preliminary experimental data the differnce during the time course of disintegration of granite and marble by water jet and pulsating water jet by vibration can be seen in fig 6,7,8.
- Deeper traces were observed in pulsating water jet as compare to the continous water-jet with the help of the SPIP6.6.0 software.
- Additionaly the effect of the acoustic emission is used to relate the technological conditions with the other control parameters to disintegrate in the materials.

Over the years WJ and AWJ has shown some technological and economical limitations in industrial application of rock and coal cutting (Sharma et al., 2010). Therefore, the technology is trending towards the disintegration of these materials at lower pressures for which pulsating WJ is the solution. This technology has potential to be used in wide variety of applications like stone carving, 3D printing, biomedical application and architectures with much more efficiency as compare to other WJ machining process.

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Abbreviations:

PWJ	- Pulsating Water jet	
AE	- Acoustic emission	
WJ	- Water-jet	
FFT	- Fast Fourier Transform	
Ra	- Mean arithmetic deviation of roughness	
Rq	- Root mean square deviation of the profile	
Rz	- Maximum height of the roughness profile	
Sq	- Root mean square roughness	
f	- Frequency	[kHz]
d	- Diameter of the nozzle	[mm]
v	- Traverse speed	[mm/s]
p	- Pressure	[MPa]
z	- Stand off distance	[mm]

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