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EFFECT OF THE ABRASIVE GRAIN SIZE ON THE CUTTING PERFORMANCE OF CONCRETE IN AWJ TECHNOLOGY

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Abstract

Abrasive waterjet (AWJ) machining is an emerging technology which enables the shaping of practically all engineering materials. Due to the advantages of AWJ machining this technology has been used in many industrial applications. In this study, effect of the abrasive size on the cutting performance of concrete cut by an abrasive waterjet was experimentally analyzed. The cutting performance was assessed in terms of the cut depth, kerf width and cutting wear zone. Due to the problem of commercially availability, two abrasive sizes were tested in three group of concrete. As a result of the study, it was found that coarse abrasive size has favourable effect on the cut depth and the kerf width, while the fine-grained abrasive produced higher cutting wear zone in all the concrete samples. Additionally; in both abrasive sizes, it was seen that there is a statistically powerful relation between the cutting performances (outputs) and the uniaxial compressive strength.

Keywords: Abrasive waterjet, Concrete, Abrasive size, Cutting performance

1. Introduction

The cutting method with waterjet is widely used in machining and processing of almost all hard and strong materials. There are generally two types of water jets; pure water jet (WJ) and abrasive water jet (AWJ). Both have unique capabilities for industrial applications. [1, 2]. High speed of the outflowing stream of water containing abrasives makes it possible to process almost every kind of materials such as rocks and building materials regardless of their composition, structure, hardness or other physical properties [3]. In abrasive waterjet cutting systems, waterjet including abrasive particles impinges onto the surface of the workpiece and material is removed by an erosion processes. Because the material is removed by erosion, it has been shown to be suitable for machining of hard to cut materials. Also, it results in very low forces which are exerted on the workpiece. Hence, it minimizes the workpiece deformation during processing and allows to machine flexible structures [4].

Waterjet cutting systems have been started to use since 1980 in several industry applications. Since then, various aspects of this cutting technique have been investigated by many scientists all over the world [5]. They have studied this technology from the units of machine to pump conditions, investigations in diverse areas of industry. A few researchers studying the cutting performances of water jet in rock cutting have dealt with mainly cutting mechanisms and defining optimum cutting parameters [6-10]. Babu and Krishnaiah [11, 12] investigated the influence of process parameters on depth of cut, surface roughness and kerf width of the granite using orthogonal array and analysis of variance approach in AWJ cutting. In addition to these researches, there are still needs to meet greater demands to develop techniques for creating surfaces with high precision in surface finish because of the increasing requirements for better surface quality and productivity.

High-speed water jet techniques are universally used for concrete processing as well. The field of application ranges from sanitation, decontamination, removing, drilling, fragmentation, trenching and roughening of concrete (Fig. 1). To optimize these processes, it is necessary to know the relation between jet and the process parameters and target parameters [13].

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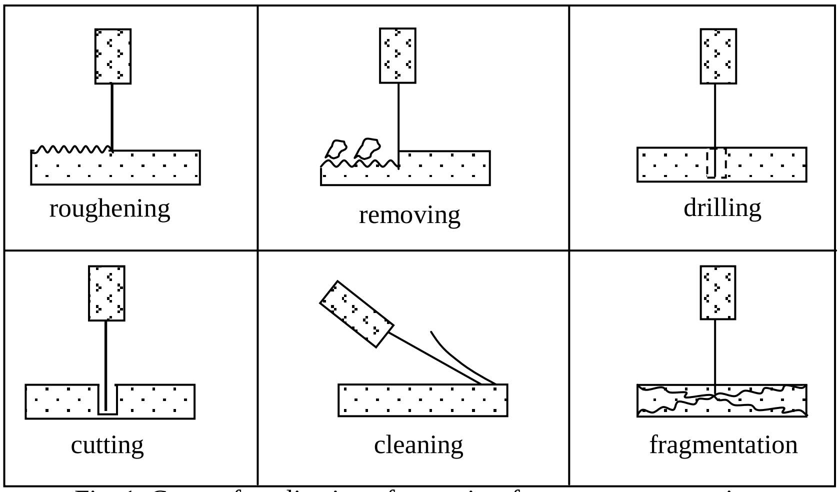

Fig. 1. Cases of application of water jets for concrete processing

The present study investigates a machinability of concrete having different aggregate size for varying the abrasive size. The cutting performance of concrete was evaluated in terms of the
cut depth, kerf width and cutting wear zone.

2. Material and Method

The experiments were conducted with a commercial abrasive waterjet apparatus illustrated schematically in Fig. 2. Details of the machine and process settings are listed in Table 1. In this research program, the process parameter under investigation is abrasive grain size. Abrasive type used in the study is garnet and it consists of chemically 36 % FeO, 33 % SiO2, 20 % Al2O3, 4 % MgO, 3 % TiO2, 2 % CaO and 2 % MnO2.

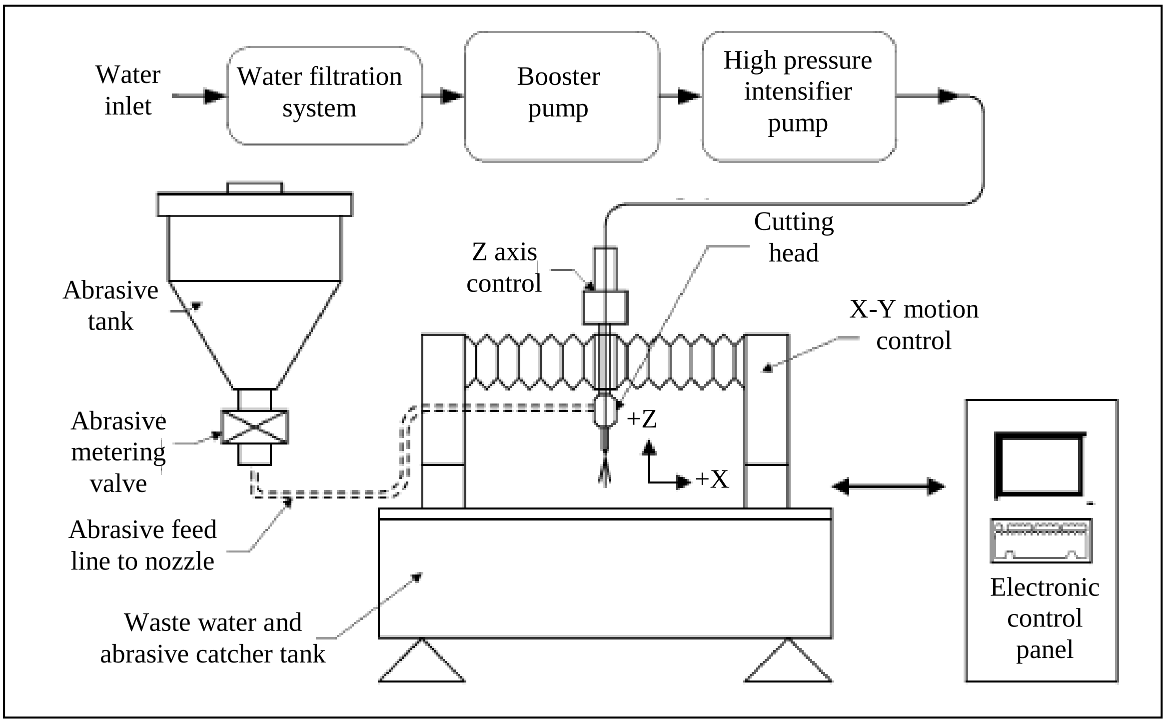

Fig. 2. A schematic illustration of the experimental set-up [modified from 14]

Table 1. Description of the AWJ process settings

Traverse speed (ms-1)	0.0008

Orifice diameter (mm)	0.3
Nozzle diameter (mm)	1.1
Nozzle length (mm)	75
Working pressure (MPa)	100
Stand-off distance (mm)	2
Abrasive flow rate(kgs-1)	0.004

All other parameters (pump pressure, standoff distance, abrasive flow rate e.g.) were maintained at nominally constant value. The concrete specimens were pre-dimensioned in the form of 12 cm wide, 14 cm long and 4 cm thick.

The concrete specimens were classified into three different sizes (Table 2) and for each size; two specimens were cut through full length [(Fig. 3(a) and (b)]. The specimens after cutting were kept from being damaged and the depths of cut, kerf widths and cutting wear zone depths were measured respectively.

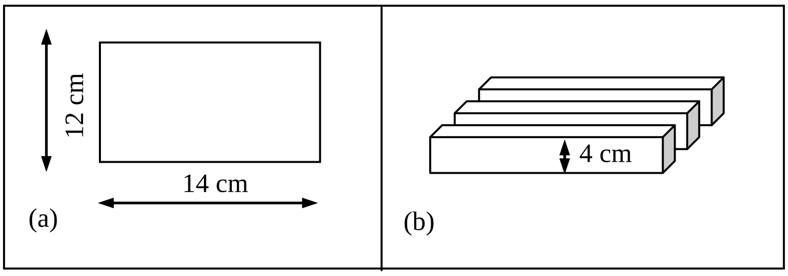

Fig. 3. (a) Dimension of the samples, (b) samples cut with AWJ

Table 2. Properties of the concrete samples

Category	Mean grain size (mm)	Uniaxial strength of samples (MPa)
Fine-grained	0.9	23
Medium-grained	1.5	34
Coarse-grained	3.6	24

3. Results and Discussion

A total of 12 concrete specimens with three different grain sizes were tested using two different abrasive grain sizes. The cut depths, kerf widths and cutting wear zone of specimens were measured by using two concrete samples for each group. The results are shown in Fig 4-6. As can be seen in Fig. 4, deeper cut depths were obtained for each grain size of concrete when using coarse-grained abrasive size. Increase of grain size in concrete resulted in keeping a steady trend after a sharp decline. In the experiments, cut depths decreased with the changing mean grain sizes of concrete from 0.9 mm to medium 1.5 mm. After 1.5 mm very little change was observed for the depth of cut.

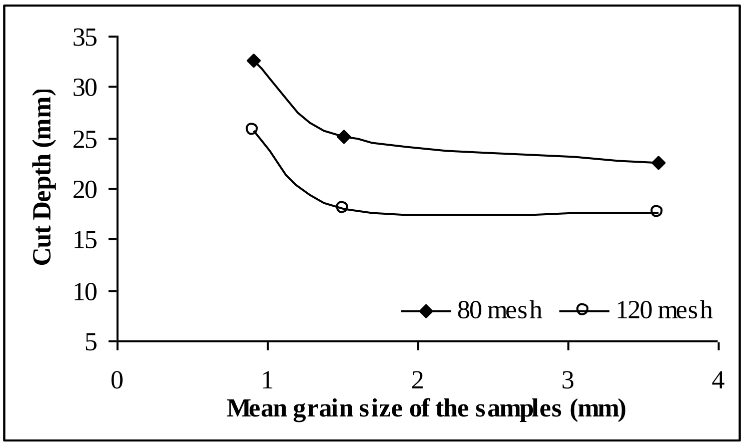

Fig. 4. Effect of the abrasive size on the cut depth of the concrete samples

Although the level of the variation remains in narrow limited range, the increase of the concrete grain size led to decrease of the kerf widths by both abrasive sizes in 0.9 mm-1.5 mm interval. After 1.50 mm, it was remained constant (Fig. 5). Similar characteristics of the changing trend were observed for the upper zone of the cut surface (defined as cutting wear zone). After 1.5 mm, the cutting wear zone depth remained nearly constant at about the depth value obtained by medium-grained concrete (Fig. 6).

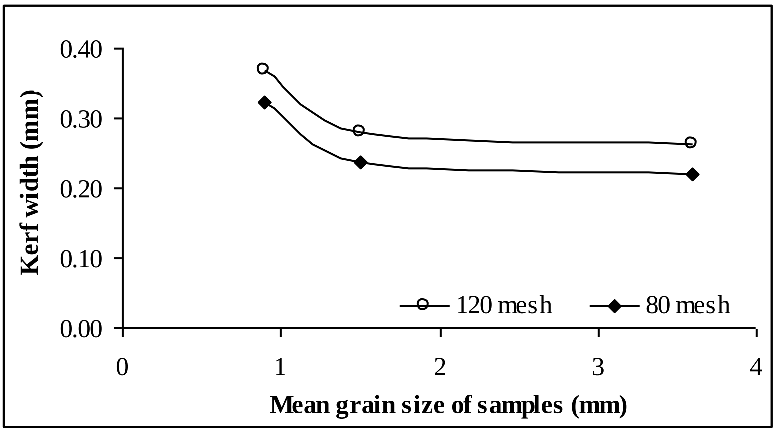

Fig. 5. Effect of the abrasive size on the kerf width of the concrete samples

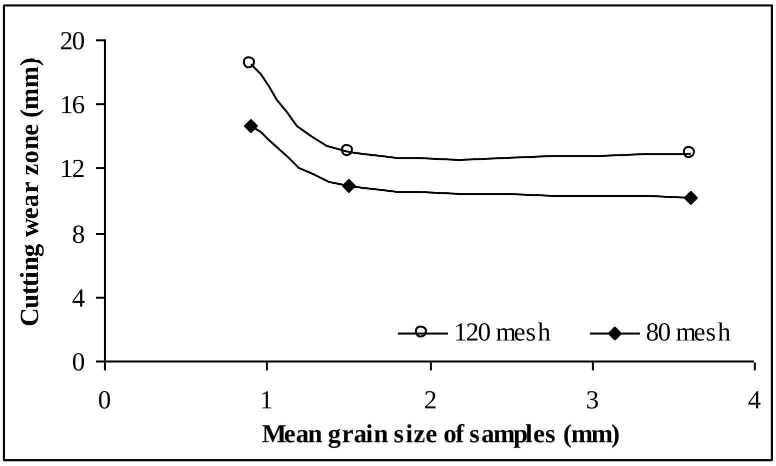

Fig. 6. . Effect of the abrasive size on the cutting wear zone of the concrete samples

Description of the cutting process or material removal by an abrasive waterjet is connected closely with the jet structure [5]. The material is mainly removed by kinetic energy of the abrasive particles of the waterjet. When the kinetic energies of abrasive particles are higher than the required energy to destruct the workpiece, material removal is occurred. The distribution of the particle kinetic energy is not uniform [15]. As it is widely known, coarse-grained particles have high kinetic energies due to their weight. When the coarse-grained particles penetrate into the work material, due to high kinetic energy, higher cut depths can be obtained (Fig. 4). At a point on the workpiece where the jet penetrates, kinetic energies of abrasive particles are high and when moving thorough the full thickness of workpiece from top to down, the abrasive particles lose their kinetic energies gradually and the cut depths are decreased.

As seen from the figures, increasing of abrasive grain size has an effect on the increase of the kerf widths. The cut depths obtained by 120 mesh abrasive size, were shallower than 80 mesh abrasive size. However, both the kerf widths and the cutting wear zones by 120 mesh were higher than 80 mesh. The cutting wear zones was equal to the nearly half of the cut depths for samples cut by 80 mesh abrasive size. In spite of this, the depths of cutting wear zone by 120 mesh abrasive were very close to the cut depths obtained. This effect is expected to be related by mainly the kinetic energies of the abrasive particles since the coarse particles have high kinetic energies due to their weight. In other words, higher cut depths can be obtained by using coarse-grained abrasive. On the other hand, the possible reasons for higher kerf widths obtained by fine-grained abrasive may be thought to be related with the scattering of particles in waterjet leaving nozzle. Between nozzle and workpiece abrasive particles tend to scatter laterally especially at long distance to the workpiece due to the high water speed and low weights of particles. Additionally; on a certain point of a material, the number of the fine-grained abrasive particle is more than the coarse-grained abrasive has. As a result, it results in wider kerf widths. These results are consistent with the findings of Hlavac [5].

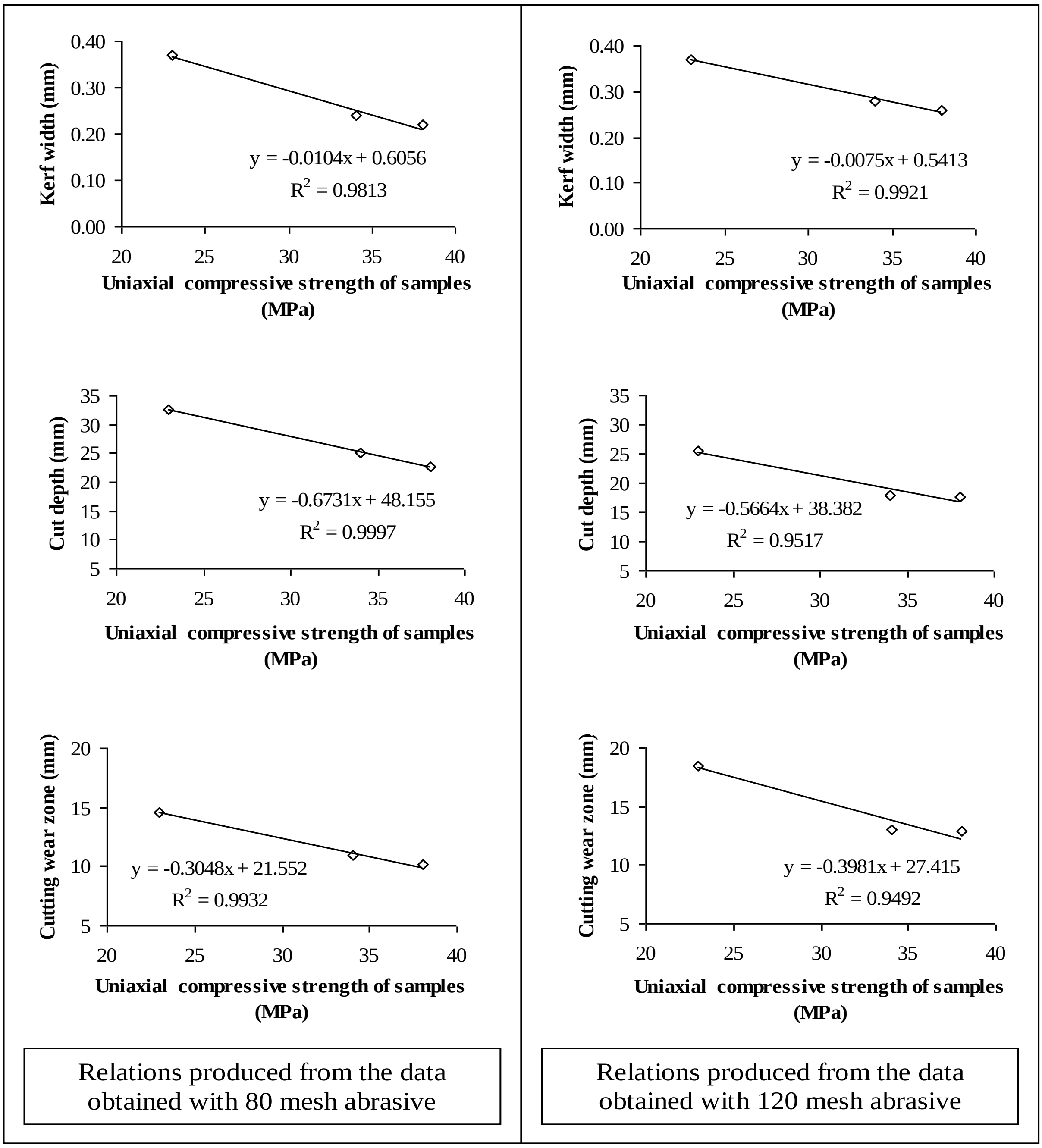

Fig.7. Relation between uniaxial compressive strength of samples and cutting performance (with 80 and 120 mesh abrasive)

From the Fig. 7, one can see that there is a powerful relation between the uniaxial strength of the samples and cutting performance. It can be concluded from the Figure that the relation is more powerful in the samples cut with 80 mesh (coarse) abrasive size. The uniaxial compressive strength of a rock is one of the prime parameter used to define the resistance of rock to the external force. Like the other cutting applications; to be able to cut the material, the cutting force should be higher than the strength of the materials in abrasive waterjet cutting application as well. When jointly considering the cutting performance of the concrete statistically, the cut depth decreased with an increase of the uniaxial compressive strength. This is an expected trend. Because when the strength of the material is higher, its cuttability would be difficult. The relation showed that the deeper cut depths were obtained with 80 mesh abrasive size due to the high velocity and weight of the individual abrasive particle in accordance with the results of the existing literature. In case of the kerf width, the relation equations are very close to each other in both 80 and 120 mesh abrasive size. However, it can be said that the powerfulness of the relation is higher in 120 mesh abrasive size than 80 mesh abrasive size has. This may be attributed to again the high strength of the material. Additionally, the cutting wear zone of the concrete samples cut with 80 mesh abrasive size is higher than the 120 mesh abrasive size. This is also an expected trend as stated by Zeng and Kim [16]. The researchers stated in their study that coarse abrasive particles cut the materials rapidly than the fine abrasive sizes can, and the cutting wear zone is higher when coarse abrasive is used. However, the surface roughness is as not good as in fine abrasive particles.

4. Conclusions

The following conclusions could be drawn from the results of the experimental study in abrasive waterjet

i. Coarse abrasive size resulted in deeper cut depths in all the concrete samples. However, when the concrete aggregate size increased, the increasing ratio of the cut depth decreased.
ii. Fine abrasive size caused wider kerf widths in all the concrete samples as an expected trend and in accordance with the results of the existing literature. Additionally, cut wear zone of all the concrete samples are higher when using fine abrasive size than coarse abrasive size do.
iii. Higher cut depths were obtained by the coarse abrasive size in fine-grained concrete, whereas the wider kerf widths and higher cutting wear zones were obtained by the fine-grained abrasive size.
iv. It was found that a powerful relation between the Uniaxial compressive strength of the samples and cutting performance, although the number of sample is few.

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