2011 WJTA-IMCA Conference and Expo
September 19-21, 2011 ● Houston, Texas

Paper

ABRASIVE GRAIN BREAKAGE PROCESS

DURING THE HIGH PRESSURE WATERJET FORMATION

A. Perec
Jet-NET International Pty. Ltd.
Perth, Western Australia

ABSTRACT

Abrasive particle size and distribution play a major role in machining and cutting efficiency of abrasive water jets. This paper presented a study of abrasive disintegration after acceleration by a 400MPa water jet through a focusing tube.
The study also analysed the influence of abrasive mass flow rates on grain disintegration and focusing tube wear rate.

Organized and Sponsored by WJTA®-IMCA®

1. INTRODUCTION

In the water jet cutting, abrasive particle size and particle size distribution directly affects cutting efficiency. Formation of the jet through an orifice and a focusing tube causes significant fragmentation of the abrasive particles. Finer abrasive particles reduce cutting efficiency.
Studies of cutting efficiency loss due to abrasive fragmentation were undertaken at the University of Missouri-Rolla [1] and others [2, 3, 4].

2. OBJECTIVES PROGRAM

To measure and compare abrasive particle size distribution after passing through a focusing tube in a 400MPa system.
Tests were carried out on two types of abrasive. Each abrasive was used on 3 different orifice to focusing tube ratios, and each combination was subjected to 5 different abrasive concentrations in the jet.
Measure Abrasive Particle Size Distribution prior to testing, collect, dewater, dry, measure and tabulate the Abrasive Particle Size Distribution after passage through the focusing tube.
The tests performed were on:

- Two types of abrasive: GMA80 & GMA120.
- Three combinations of Orifice/Focusing Tube ratios: 0.25/0.75; 0.33/1.02 & 0.33/0.76
- Five abrasive concentrations (by weight) in the jet: 15%, 17.5%, 20%, 22.5% & 25%.

3. TESTED MATERIAL

The study used GMA Garnet abrasives supplied by GMA Garnet Pty Ltd, Western Australia. The chemical composition of abrasives is shown in Table 1, and physical/chemical properties in Table 2.

Table 1. GMA Garnet composition and information on ingredients

Chemical name	CAS Number	Proportion (weight %)
Almadine Garnet $Fe_3Al_2(SiO_4)_3$	1302-62-1	Greater than 97.0
Ilmenite $FeTiO_3$	103170-28-1	Less than 2.0
Calcium Carbonate $CaCO_3$	471-34-1	Less than 1.5
Free Quartz SiO_2	14808-60-7	Less than 0.5
Zircon $ZrSiO_4$	149040-68-2	Less than 0.2

Table 2. GMA Garnet Physical and chemical properties

Apperance:	Pink to red coloured free flowing sand
Odour	Odourless
pH	Neutral
Melting point	~1250°C
Radioactivity	Not detectable above background levels
Density	4100 kg/m^3
Buld density	2300 kg/m^3
Hardness	7.5 - 8 Mohs
Solubility in water	Insoluble
Shape of natural grains	Sub-angular

Abrasives GMA80 and GMA120 were used to test. Fraction distribution shows the Fig.1. and detailed statistical parameters [6] Tab. 3.

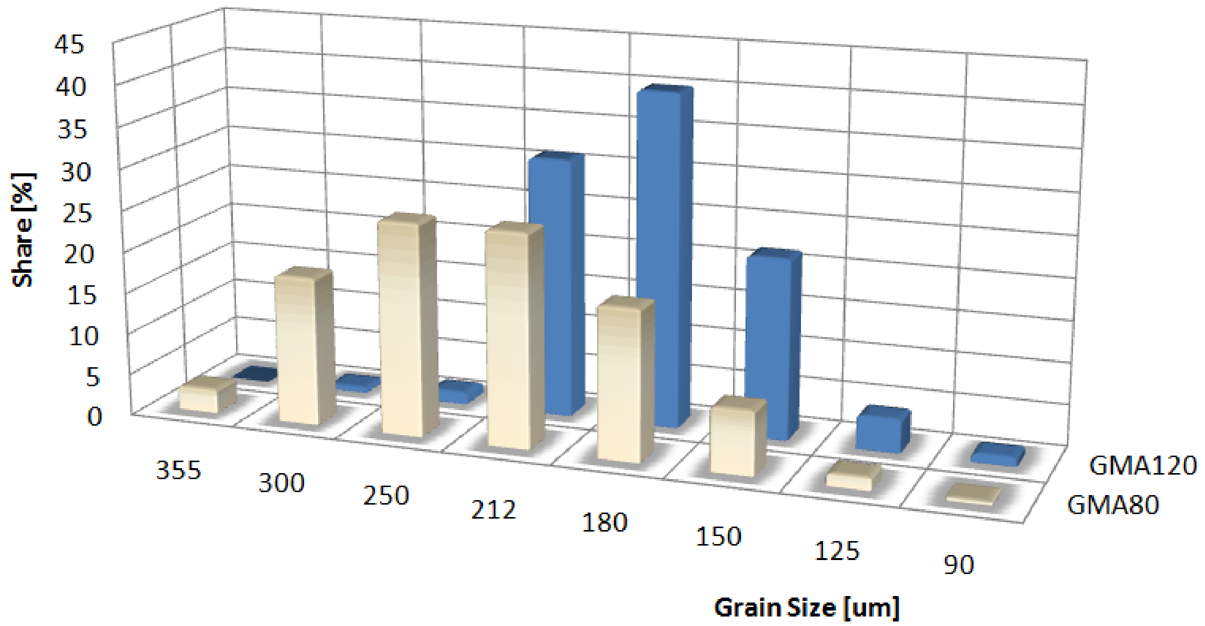

Figure 1. Typical size analysis of GMA Garnet

Table 3. GMA Garnet statistical properties

		GMA80	GMA120
	SAMPLE TYPE:	Unimodal, Very Well Sorted	Unimodal, Very Well Sorted
	TEXTURAL GROUP:	Gravel	Gravel
	SEDIMENT NAME:	Fine Gravel	Fine Gravel
METHOD OF MOMENTS Arithmetic (μm)	MEAN ($\bar{x}_a$):	239.5	198.8
	SORTING (σ_a):	66.29	31.37
	SKEWNESS (Sk_a):	-1.158	0.118
	KURTOSIS (K_a):	5.825	4.070
METHOD OF MOMENTS Geometric (μm)	MEAN ($\bar{x}_g$):	204.7	195.5
	SORTING (σ_g):	2.574	1.178
	SKEWNESS (Sk_g):	-5.145	-0.589
	KURTOSIS (K_g):	29.12	4.246
METHOD OF MOMENTS Logarithmic (ϕ)	MEAN ($\bar{x}_\phi$):	2.000	2.354
	SORTING (σ_ϕ):	0.469	0.236
	SKEWNESS (Sk_ϕ):	-1.936	0.589
	KURTOSIS (K_ϕ):	10.35	4.246
FOLK AND WARD METHOD (μm)	MEAN (M_G):	244.5	196.3
	SORTING (σ_G):	1.273	1.175
	SKEWNESS (Sk_G):	-0.039	-0.098
	KURTOSIS (K_G):	0.920	0.917
FOLK AND WARD METHOD (ϕ)	MEAN (M_Z):	2.032	2.349
	SORTING (σ_I):	0.348	0.232
	SKEWNESS (Sk_I):	0.039	0.098
	KURTOSIS (K_G):	0.920	0.917
FOLK AND WARD METHOD (Description)	MEAN:	Fine Sand	Fine Sand
	SORTING:	Very Well Sorted	Very Well Sorted
	SKEWNESS:	Symmetrical	Symmetrical
	KURTOSIS:	Mesokurtic	Mesokurtic
	MODE 1 (μm):	231.0	196.0

4. TEST EQUIPMENT

The equipment used was a KMT Intensifier type I50, 2 axis CNC table type ILS55 by Techni Waterjet with computer control system (Fig. 2).
To capture abrasives after its exit from the focusing tube, a special receiver was used (Fig. 3). The receiver was designed to collect the abrasives and to prevent any further particle disintegration after leaving the focusing tube. The bottom PVC receiver was covered by a steel plate to prevent perforation. No signs of wear were observed on the protective plate after conclusion of testing.
For establishing the particle size distribution of the abrasive, Retsch sieving equipment was used. The mass of abrasive remaining on the sieves was weighed on the digital lab scales.
Microscopic photos of abrasive particles were taken on a microscope Olympus SZ-40 equipped with a digital camera MD1800 Am Scope type with 8MB CCD.

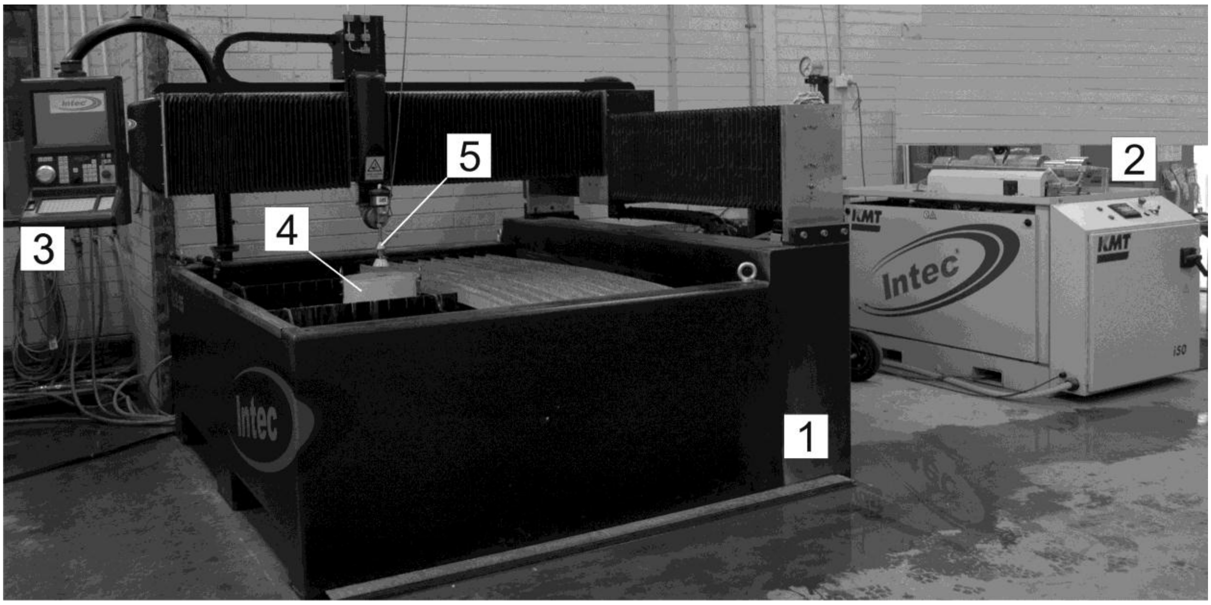

Figure 2. Testing stand: 1) Cutting table, 2) Intensifier, 3) Control Unit,4) Catcher, 5) Cutting Head

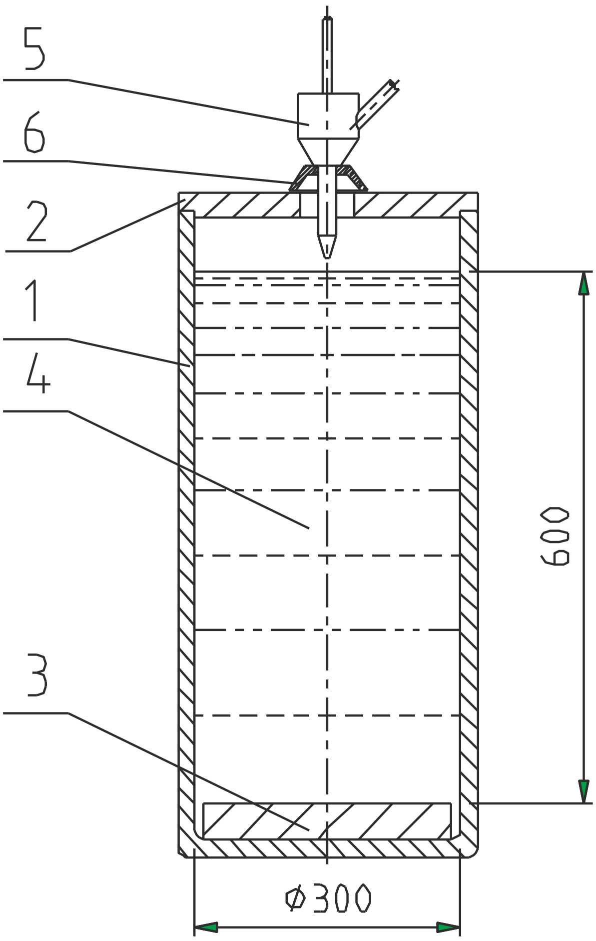

Figure 3. Catcher for abrasive jet: 1) Tank, 2) Tank Cap, 3) Mild Steel Shield, 4) Water, 5) Cutting Head, 6) Rubber Head Cap

5. TEST RESULTS

5.1. Disintegration of GMA80 grains

The results of the study of GMA80 abrasive fractured during formation of jets at a pressure of 390MPa through a 0.25mm dia. Orifice and 0.76mm ID focusing tube are shown in Fig. 4.
The largest fraction (almost 25%) was smaller than 53µm. Overall a very significant particle size decrease was observed.
Abrasive mass flow rate (concentration of abrasive in the stream) had almost no impact on particle fragmentation.

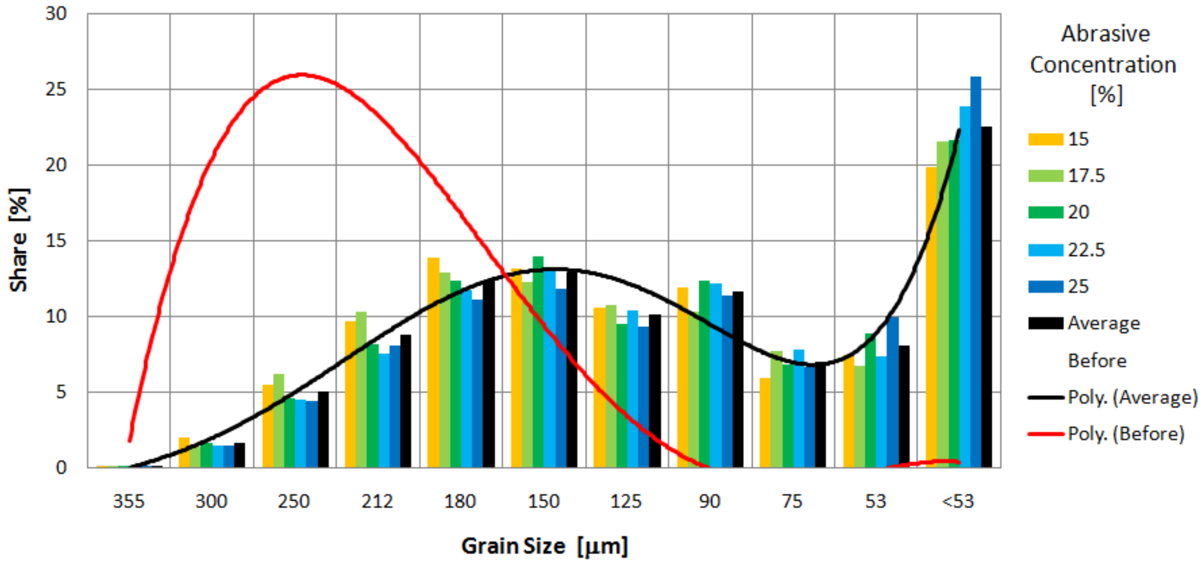

Figure 4. Disintegration of GMA80 after passing through cutting head with water nozzle ID 0.25mm and focusing tube ID 0.76mm, Pressure 390MPa.

Fig. 5 shows abrasive fractured during formation of jets at a pressure of 390MPa through a 0.33mm dia. Orifice and 1.02mm ID focusing tube.
The largest fraction (almost 20%) was smaller than 53µm. Overall a very significant particle size decrease was observed.
There is no significant effect of abrasive concentration on the abrasive disintegration in tested range (from 15% to 25%).

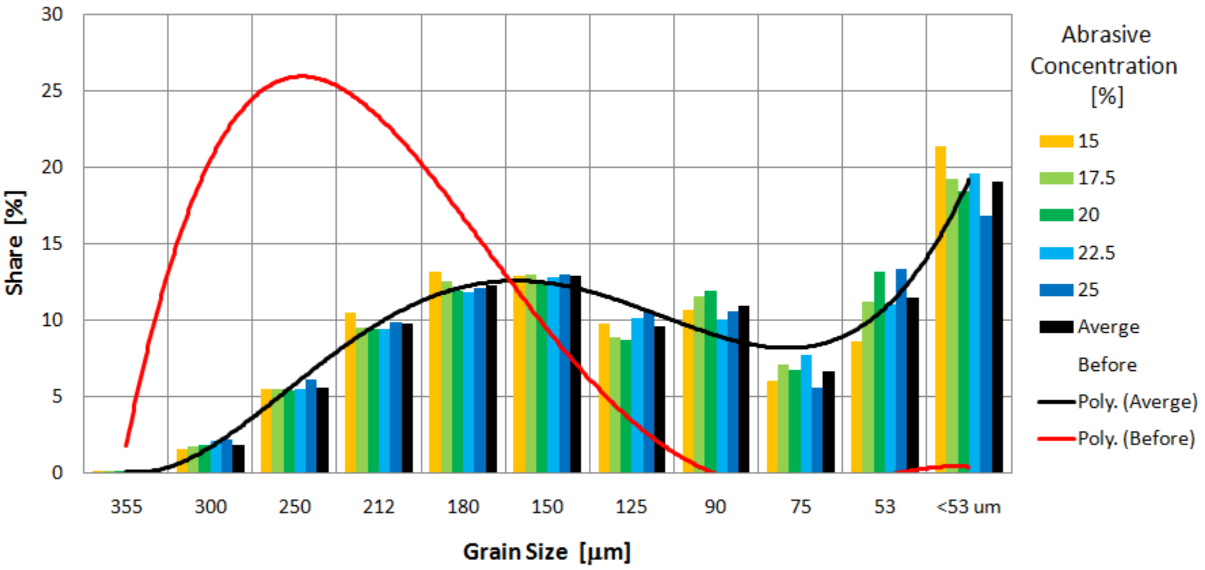

Figure 5. Disintegration of GMA80 after passing through cutting head with water nozzle ID 0.33mm and focusing tube ID 1.02mm. Pressure 390MPa.

Fig. 6 shows abrasive fractured during formation of jets at a pressure of 390MPa trough a 0.33mm dia. Orifice and 0.76mm ID focusing tube.
The largest fraction (almost 25%) was smaller than 53μm. Overall a very significant particle size decrease was observed.
There is no significant effect of abrasive concentration on the abrasive disintegration in tested range (from 15% to 25%).

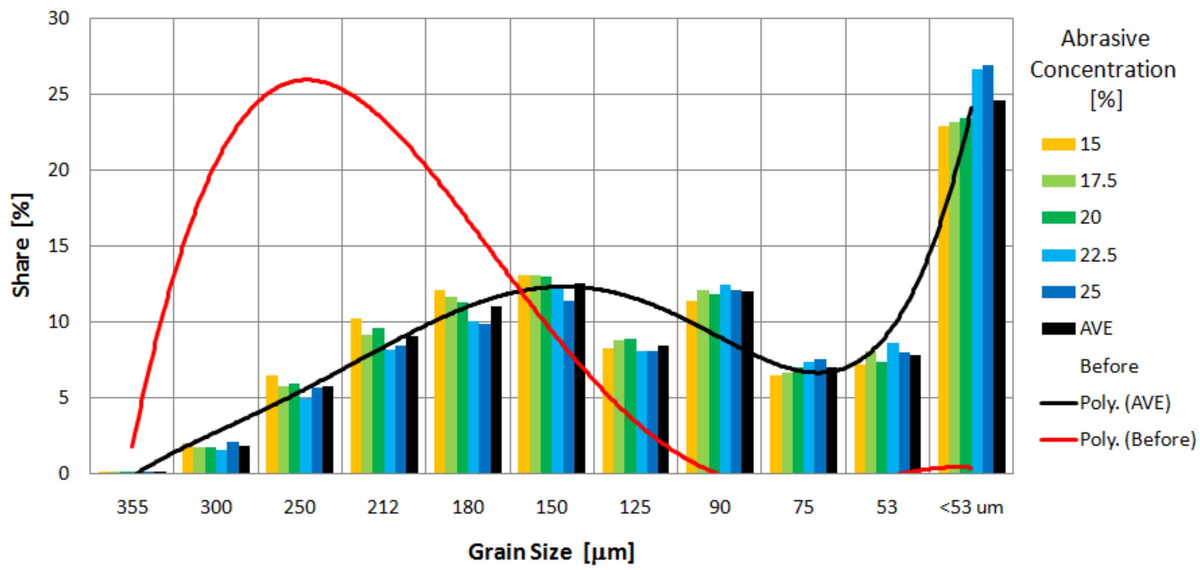

Figure 6. Disintegration of GMA80 after passing through cutting head with water nozzle ID 0.33mm and focusing tube ID 0.76mm. Pressure 390MPa.

Figure 7a. shows microscopic abrasive GMA80 before acceleration through the focusing tube.

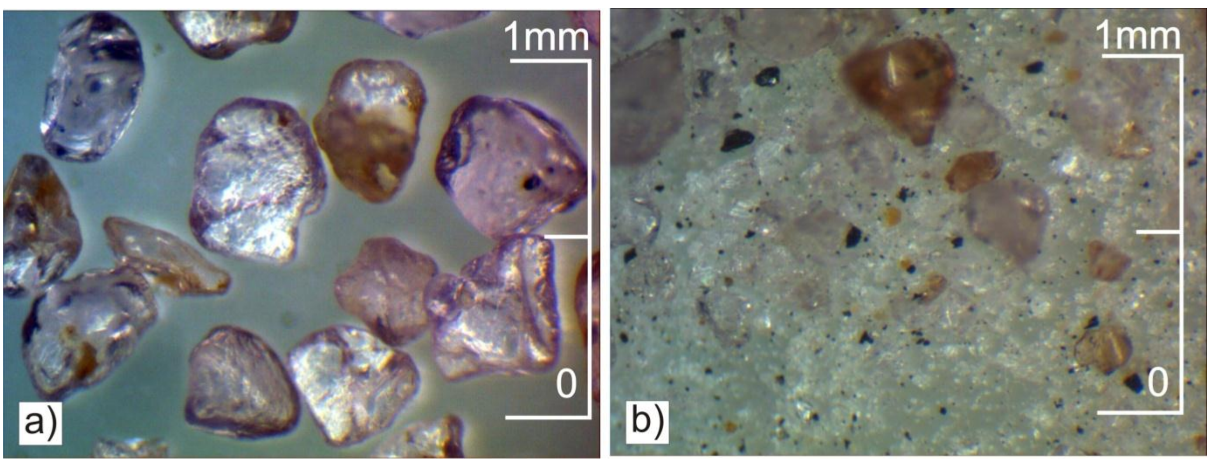

Figure 7. Abrasive grains GMA80: a) before b) after forming in cutting head. Magnification 60x.

Grains have an isometric shape, with oval, rounded edges and dimensions similar to each other, as can be seen.

Figure 7b shows abrasive particles after leaving the focusing tube. One can observe different size grains, mostly isometric in shape, but with sharp edges. Most grains are fine. Among them, you can see a few grains with larger dimensions.

5.2. Disintegration of GMA120 Grains

Fig. 8 shows abrasive fractured during formation of jets at a pressure of 390MPa through a 0.25mm dia. Orifice and 0.76mm ID focusing tube.

The largest fraction (almost 25%) was smaller than 53μm. Overall a very significant particle size decrease was observed.

There is no significant effect of abrasive concentration on the abrasive disintegration in the tested range (from 15% to 25%).

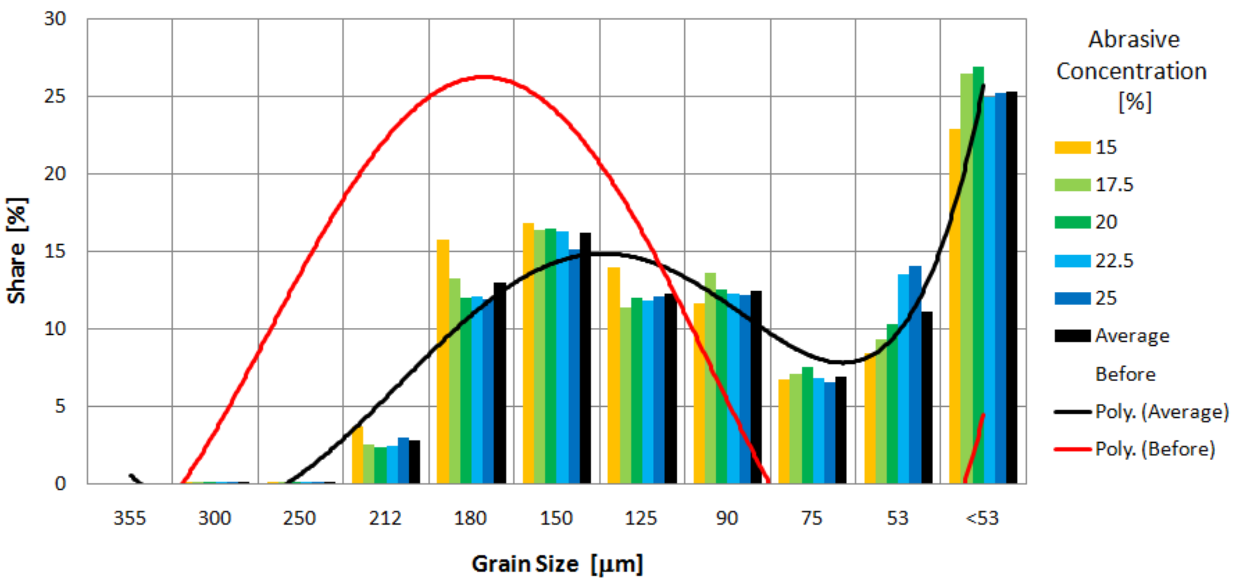

Figure 8. Disintegration of GMA120 after passing through cutting head with water nozzle ID 0.25mm and focusing tube ID 0.76mm. Pressure 390MPa.

Fig. 9 shows abrasive fractured during formation of jets at a pressure of 390MPa through a 0.33mm dia. Orifice and 1.02mm ID focusing tube.
The largest fraction (almost 28%) was smaller than 53μm. Overall a very significant particle size decrease was observed.
There is no significant effect of abrasive concentration on the abrasive disintegration in tested range (from 15% to 25%).

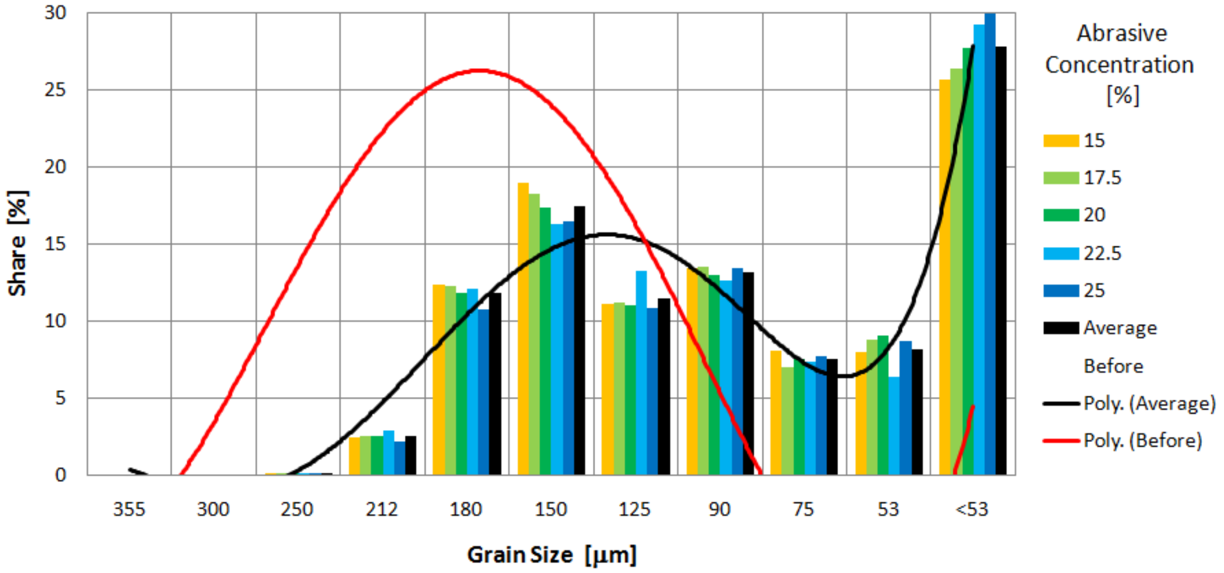

Figure 9. Disintegration of GMA80 after passing through cutting head with water nozzle ID 0.33mm and focusing tube ID 1.02mm. Pressure 390MPa.

Fig 10a. shows GMA120 abrasive before acceleration through the focusing tube. Grains have an isometric shape, with oval, rounded edges and are reasonably uniform in size, as can be seen.

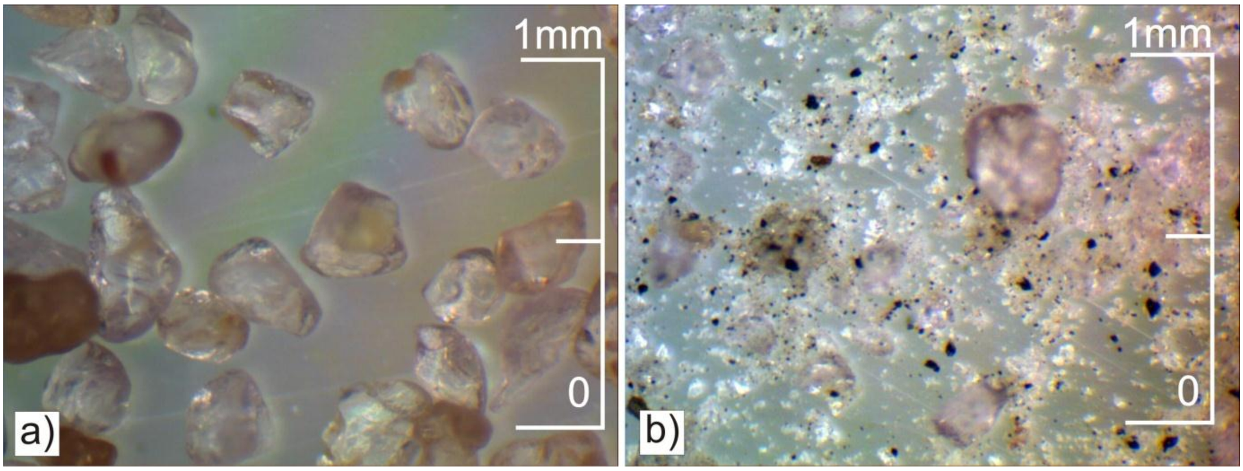

Figure 10. Abrasive grains GMA120: a) before b) after forming in cutting head. Magnification 60x.

After leaving the focusing tube abrasive grains are significantly fragmented (Fig. 10b). One can observe different size grains, mostly isometric in shape, but with sharp edges. Most grains are fine. Among them, you can also see a single grain with larger dimensions.

5.3. Average Distribution after Jetting

Fig 11. shows an average particle size distribution of GMA80 and 120 before and after acceleration through the following orifice/focusing tube ratios.
0.25mm/0.76mm,
0.33mm/0.76mm,
0.33mm/1.02mm.

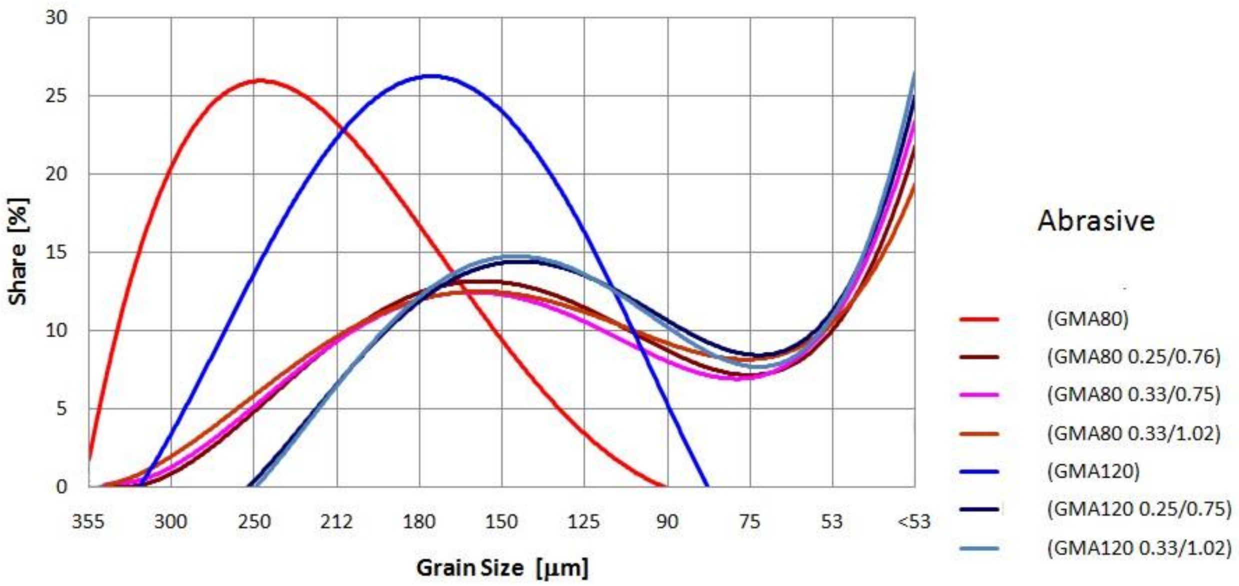

Figure 11. Particle Size Distribution of GMA80 and GMA120 before and after passing through various orifice/focusing tube ratios at 390 MPa.

The graphed results indicate that the difference in particle size distribution between the two abrasives decreases after acceleration through the orifice and focusing tube. Assuming there is a correlation between particle size and cutting efficiency, then the results would suggest that there would be only a marginal advantage in using a smaller mesh abrasive for a venturi type, high pressure water cut.

5.4. Wear of Focusing Tube

In parallel to the study of the abrasive fragmentation in the cutting head, focusing tube wear [5] at work tests were conducted. Fig. 12 shows the wear of focusing tubes in the function of the amount of GMA80 and GMA120 abrasive, which flowed through the focusing tube. Wear is similar and proportional to the amount of abrasive for both abrasives.

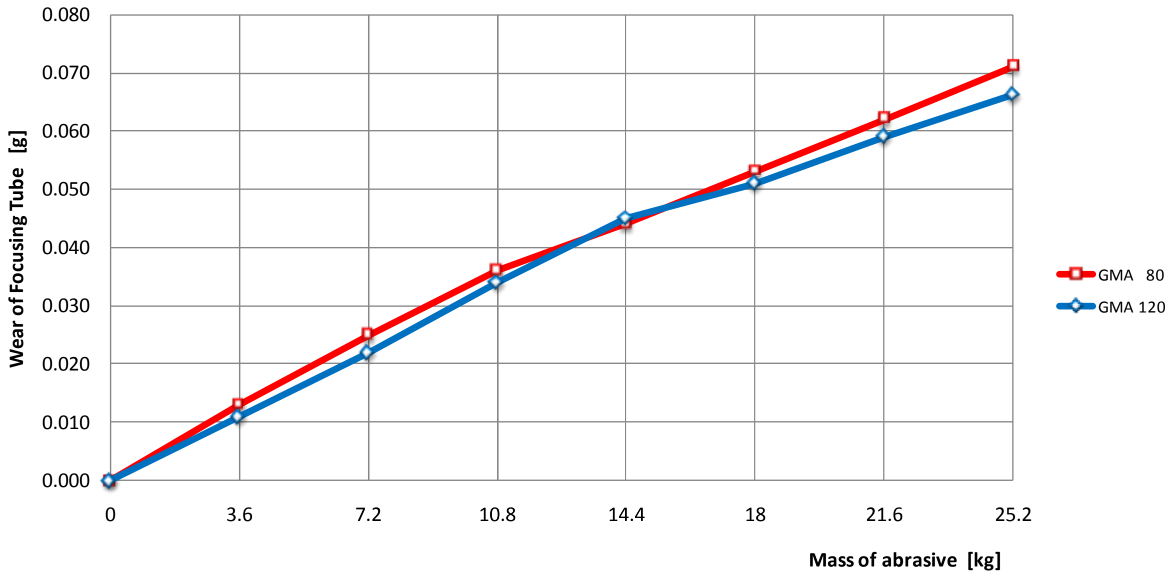

Figure 12. Wear of focusing tube. Tube material: ROCTEC100, Abrasive: GMA Garnet.

A Specified Focusing tube durability co-efficient was used. It was defined as the ratio of weight loss and abrasive mass that resulted in the loss:

$$x = \frac{\Delta \mathrm{f}}{\Delta \mathrm{m}} \qquad (1)$$

where:

x - focusing tube durability co-efficient [g/g]

Δf - mass loss of focusing tube [g],

Δm - abrasive mass [g].

Durability co-efficient for GMA 80 is $3.1*10^{-6}$ and for GMA120 is $2.9*10^{-6}$.

7. CONCLUSIONS

On the basis of the undertaken study and analysis of results the following conclusions were drawn:

- A large fragmentation occurs during the acceleration through the orifice and the focusing tube. Almost 25% of abrasive was fragmented to below 53 microns.
- The difference in particle size distribution decreases after acceleration through the orifice and the focusing tube.
- Abrasive concentration (in the range of 15 to 25%) has almost no effect on fragmentation.
- Orifice to focusing tube ratio plays a very small part in the degree of fracturing of the abrasive.
- A durability co-effiecient for the GMA abrasive exists in the range 2.9 - $3.1*10^{-6}$ [g/g].

8. ACKNOWLEDGEMENTS

The author would like to thank the management of GMA Garnet Pty Ltd. for the use of their abrasive, and help in the research program.

9. REFERENCES

[1] Galecki G., Mazurkiewicz M.: Hydroabrasive Cutting Head - Energy Transfer Efficiency. 4th US Water Jet Conference, ASME Journal of Engineering Materials and Technology, 111, pp. 221-228.

[2] Hlavač L. et al: Comminution of material particles by water jets — Influence of the inner shape of the mixing chamber. International Journal of Mineral 2010. Processing Volume 95, Issues 1-4, pp 25-29.

[3] Junkar M., Jurisevic B., Fajdiga M. and Grah M.: Finite element analysis of single-particle impact in abrasive water jet machining. International Journal of Impact Engineering Volume 32, Issue 7, July 2006, Pages 1095-1112.

[4] Ohlsen, J. 1997 Recycling on Ferststoffen beim Wasserabravstrahlverfahren. VDI Fortschritt-Berichte, Reihe 15, Nr. 175.

[5] Perec A.: Possibilities of machining materials by hydroabrasive waterjet under 1000 MPa pressure. THE 3rd International Conference on Machining and Measurements of Sculptured Surface. Kraków, Poland 2003, pp. 435-444.

[6] Pye, K. and Blott, S.J. (2001) GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. *Earth Surface Processes and Landforms* 26, 1237-1248.