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Recycling and Recharging of Supreme Garnet in Abrasive Waterjet Machining

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Abstract

Abrasive waterjet (AWJ) technology is widely used for cutting technical materials, cleaning contaminated surfaces, polishing hard-to-machine materials, etc. However, its main disadvantage is high cutting cost. Therefore, recycling and recharging abrasives used in the AWJ cutting process have been subject to many studies. This chapter presents a study on the recycling and recharging of Supreme garnet (or IMC garnet) in abrasive waterjet machining. In this study, the reusability of the recycled and recharged garnet was explored. Also, the cutting performance and the cutting quality of the recycled and recharged abrasive were investigated. Finally, the optimum particle size for recycling and recharging was found.

Keywords: abrasive waterjet (AWJ), abrasive recycling, abrasive recharging

1. Introduction

Abrasive waterjet (AWJ) technology is a recent non-traditional machining process. In this technology, a very high-pressure beam of water and abrasives is used for cutting difficult-to-machine materials, milling slots, cleaning contaminated surfaces, etc. In practice, AWJ machining has been developed from waterjet machining. The earliest use of the water beam in coal mining started in the former Soviet Union and New Zealand [1]. Then, waterjet beam was used for cutting wood in the 1950s [4]. Nevertheless, it was not until 1971 that the first waterjet cutting machine was applied [2]. After that, the abrasive waterjet cutting method was invented by adding abrasives into a beam of pure waterjet. Since then, abrasive waterjet was first used to cut glass, steel, and concrete in 1980. The invention of AWJ [3] led to a huge expansion of applications of cutting a wide variety of materials.

AWJ machining has many advantages over other nonconventional techniques [4]:

- It can cut a wide range of materials including titanium, stainless steel, aerospace alloys, glass, plastics, ceramics, and so on.
- It can cut net-shaped parts and near net-shaped parts.
- There are no heat-affected areas; thus, no structural changes in work materials occur because no heat is generated in the cutting process.
- It is particularly environmentally friendly as it does not cause any cutting dust or chemical air pollutants.
- Only one nozzle is needed to machine various types of work materials and workpiece shapes.
- AWJ machining can be easily automated, and therefore it can be run with unmanned shifts.

2. Abrasive waterjet system

Figure 1 shows a typical AWJ entrainment system. There are four main parts in the system. They are the water preparation system, the pressure generation system, the jet former, and

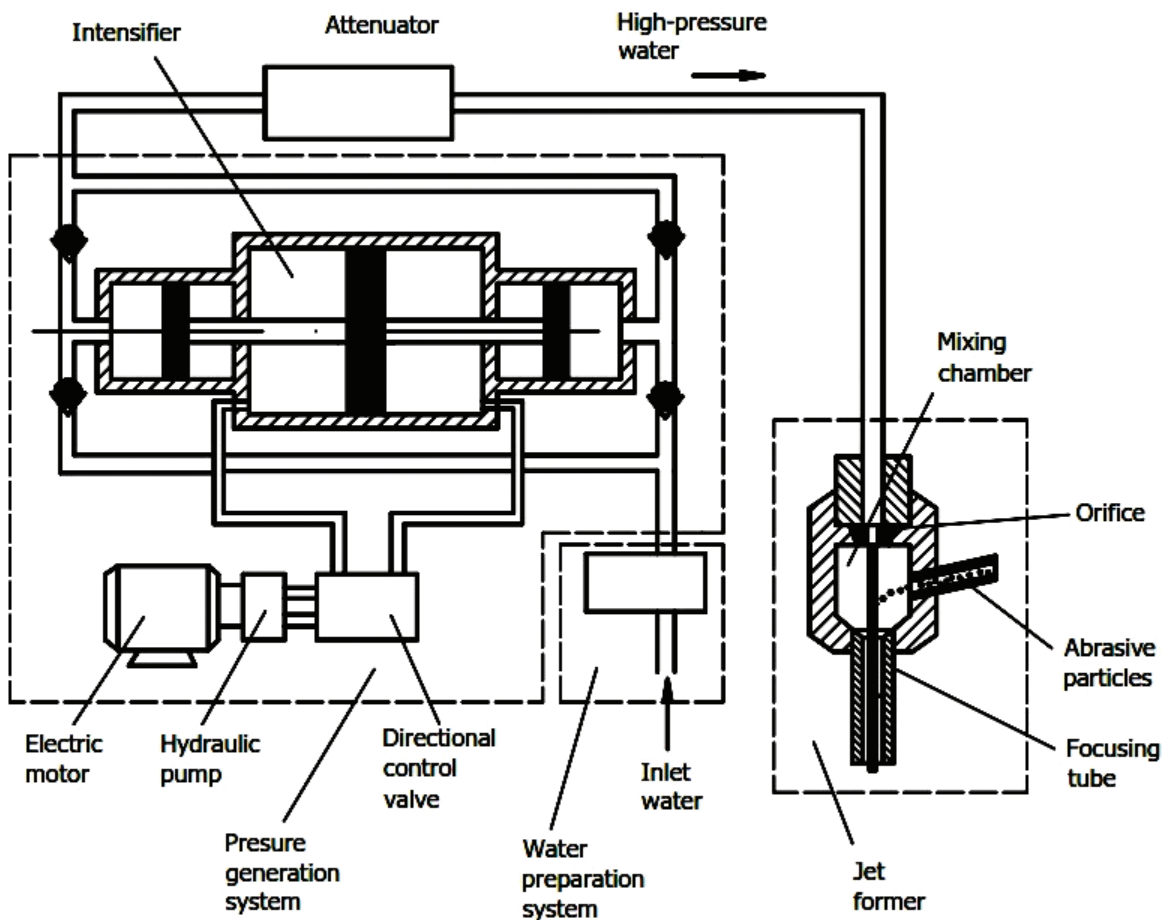


Figure 1. Schema of an AWJ machining system [4].

the abrasive supply system. An abrasive waterjet entrainment system mixes abrasives with the waterjet in a mixing chamber. The abrasive particles are accelerated by the high-velocity water stream and then leave the focusing tube (or the nozzle) with the stream. The high-velocity beam of water and abrasives is used for cutting harder materials such as stainless steel, glass, ceramics, titanium alloys, composite materials, and so forth.

3. Challenges in abrasive waterjet technology

Although AWJ machining has a number of advantages as described in Section 1, a considerable disadvantage of this technology is its relatively high cutting cost. Therefore, the reduction of the machining cost is a significant challenge in this technology.

In order to reduce AWJ machining cost, there are two possible solutions including optimization of the machining process and abrasive recycling. For the first solution, until now, there have been many studies in optimizing AWJ's factors that include jet parameters (e.g., water pressure, orifice diameter, focusing tube diameter, focusing tube length, abrasive mass flow rate, abrasive size, abrasive shape, and abrasive type) and cutting parameters (e.g., the stand-off distance, the work material, and the feed speed).

For optimum selection of focusing tube and orifice diameters, H. Blickwedel [5] introduced an optimum ratio between the focusing tube diameter and the orifice diameter. Zeng and Munoz [6] also reported the optimum combination of focusing tube/orifice for the highest AWJ cutting performance. The optimum focusing tube length for maximum depth of cut was proposed by Blickwedel [5]. Hashish [7] noted that the depth of cut and the kerf width both depend on the length of the focusing tube. In addition, a new way for using the focusing tube in order to get the minimum cutting cost was proposed [8].

Numerous studies have been carried out on optimum abrasive mass flow rate. The optimum abrasive mass flow rate for the maximum cutting performance (or for the maximum depth of cut) depends on many parameters including the water pressure [9–11], the orifice diameter [9, 11], the focusing tube diameter [9, 10, 12], and the focusing tube length [10].

The effects of other parameters on the depth of cut have also been investigated. Those are the abrasive particle sizes [13] and the standoff distance [5, 14]. For getting the minimum cutting time, the minimum cutting cost, and the maximum profit rate, Vu Ngoc Pi [4] carried out a study on AWJ optimization. In the study, models for determination of the optimum abrasive mass flow rate and the optimum nozzle exchanged diameter were proposed.

The other solution to enhance AWJ cutting cost is abrasive recycling. So far, there were several studies on this area. Labus et al. [15] presented a fundamental research on the influence of the process parameters on the particle size distribution after the mixing process and after the cutting process. The authors found that the water pressure from 0 to 205 MPa had more influences on the fraction of abrasive particles than the pressure from 274 to 342 MPa. Furthermore, the geometry of the mixing chamber affected the distribution of abrasive particle size. It was also noted that the particle fraction was not connected to the length of the mixing tube.

Louis et al. [16] explored the influences of cutting parameters on the fragmentation of abrasive particles after penetration to the workpiece. It was mentioned that after the workpiece, the average size of particles was smaller than that after the focusing tube. In addition, the authors found that the particle fragmentation depended on the workpiece materials. For instance, the particle size after cutting stainless steel was smaller than after cutting aluminum. Furthermore, the fragmentation after workpiece of different abrasive materials was inspected. The authors reported that olivine produced a slightly smaller average particle size than garnet [16].

For evaluation of the fragmentation of abrasive particles, Ohlsen [13] introduced a “disintegration number” in a systematic study on the recycling of Barton garnet. In the study, the effects of different process parameters on the magnitude of the disintegration number were investigated, such as the water pressure, the abrasive mass flow rate, the abrasive particle diameter, the focusing tube diameter, and the focusing tube length.

Another study on the abrasive recycling was performed for a local garnet from India [17]. In this study, the reusability of the garnet was investigated with four recycling cycles. It was found that the recycling capacity (or the reusability) of the first, the second, the third, and the fourth recycling was 81, 49, 26, and 15%, respectively. In addition, the influences of recycled abrasives on the cutting performance and the cutting quality were explored.

In order to increase and preserve the cutting performance of recycled abrasives, new abrasives are added into recycled abrasives. This process is called recharging of abrasives. Kantha Babu and Krishnaiah Chetty [18] announced the results of an abrasive recharging study. It was reported that an increase of the added new abrasives up to 40% led to a significant increase of the depth of cut and a slight increase thereafter. Subsequently, in order to get the maximum depth of cut, the recharging at 40% of the recycled abrasive mass was recommended. Besides, the percentage of added abrasives as well as the cutting performance and the cutting quality of recharged abrasives was examined.

Vu Ngoc Pi et al. [19] carried out a study on the recycling and recharging of GMA abrasive. In the research, the reusability of GMA abrasive after the first cut and second cut was explored. In addition, the reusability of the recharged abrasives was explored. Furthermore, the cutting performance and the cutting quality of both recycled abrasive and recharged abrasive were investigated. The optimal particle sizes for the recycling and the recharging of GMA garnet were also proposed.

The cutting performance and the economics when using recycled and recharged GMA abrasives were evaluated in another study of Vu Ngoc Pi [4]. It was concluded that the cutting performance when cutting with recycled and recharged abrasives is higher than that when cutting with the new abrasive (about 17% when cutting with recycled abrasives and 10% when cutting with recharged abrasive). Also, cutting with those abrasives can reduce the total cutting cost and increase the profit rate significantly [4].

4. Recycling and recharging of supreme garnet

In this chapter, the recycling and recharging of Supreme garnet are investigated. In the study, the reusability of the garnet, the cutting performance, and the cutting quality of the recycled

and recharged abrasive are explored. Also, the optimum particle size for getting the maximum cutting performance for both recycling and recharging of Supreme garnet is determined.

4.1. Reusability of supreme garnet

4.1.1. Experimental setup

Figure 2 describes the experimental setup for determination of the reusability of the garnet. The cutting system consists of a M23120B Flow Waterjet machine and a cutting head with a focusing tube diameter of 1.02 mm and an orifice diameter of 0.33 mm. The workpiece material is SUS 304, the abrasive is IMC garnet #80, and the cutting regime is as follows: the water pressure of 350 MPa, the abrasive mass flow rate of 300 g/min, and the feed speed of 90 mm/min. For abrasive sieving, a sieve shaker and 11 sieves (ISO3310-1) are used. The nominal aperture sizes of the sieves are 63, 75, 90, 106, 125, 150, 180, 212, 250, 300, and 355 μm , respectively. To investigate the reusability of the first recycling, the abrasives after cutting are collected, washed, dried, chips separated, sieved, and sorted.

In AWJ cutting process, the fragmentation (or the breaking) of abrasive particles occurs in two stages [4]: during mixing process (due to the interactions between particles and the mixing chamber walls and focusing tube and between particles with each other) and during the cutting process (due to the interactions between particles with the workpiece and particles

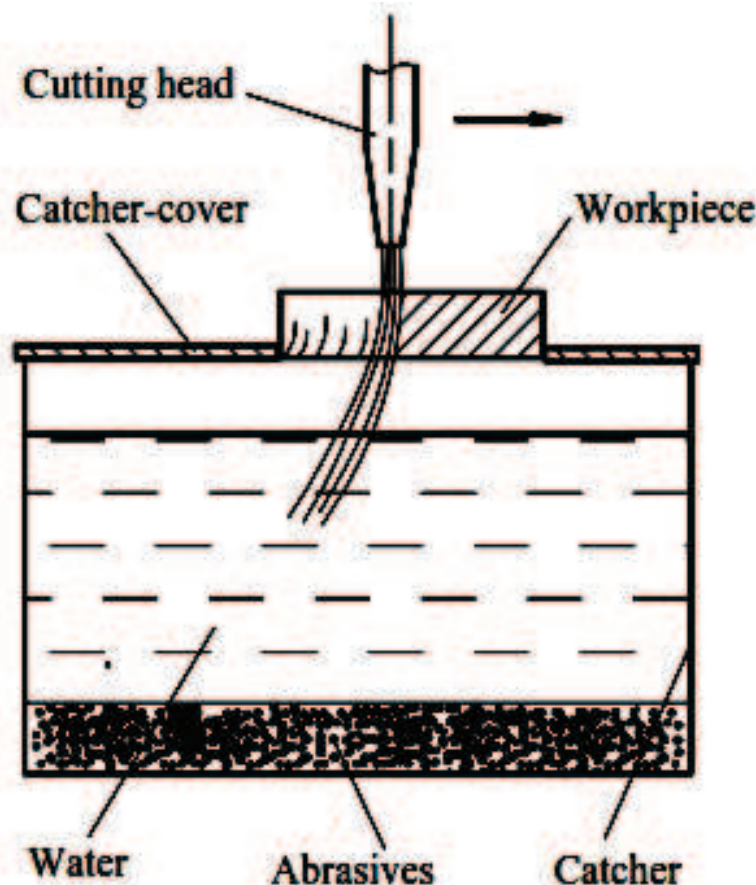


Figure 2. Experimental setup for collecting abrasives [4].

with each other). Therefore, studying the abrasive recycling needs an understanding of the fragmentation of abrasive particle in both above stages.

The experiment for investigating the abrasive fragmentation after focusing tube is the same as in **Figure 2**. However, in this experiment, no workpiece was used. After coming into water tank, the abrasives were collected and dried. After that, they were sieved and sorted into different sizes. The experiment was performed with four recycled abrasive samples (with particle sizes larger than 90, 106, 125, and 150 μm) and a new Supreme garnet sample.

4.1.2. Results and discussions

Table 1 presents the reusability of the garnet after the first cut. Similar to GMA garnet [19], the reusability of Supreme garnet decreases with the increase of the recycled particle size. It is noted that Supreme garnet can be reused better than GMA garnet. As it can be seen in **Table 1**, the reusability of Supreme garnet (with particles larger 90 μm) is 58.86%, while it is 53.64% with GMA garnet [19].

Figure 3 describes the relation between retained particle mass and the particle size after the mixing process. It is found that, with all abrasive samples, the retained particle mass with the size larger than 150 μm is nearly the same. Nevertheless, with the size smaller than 150 μm , the retained particle mass is significantly different from each other. Also, the retained particle mass of all recycled abrasive samples with the size smaller 150 μm is higher than that of the new ones.

Sieve size (μm)	>90	>106	>125	>150	>180	>212	>250
Reusability (%)	58.86	53.4	47.0	38.7	27.4	16.4	4.6

Table 1. Reusability after the first cut.

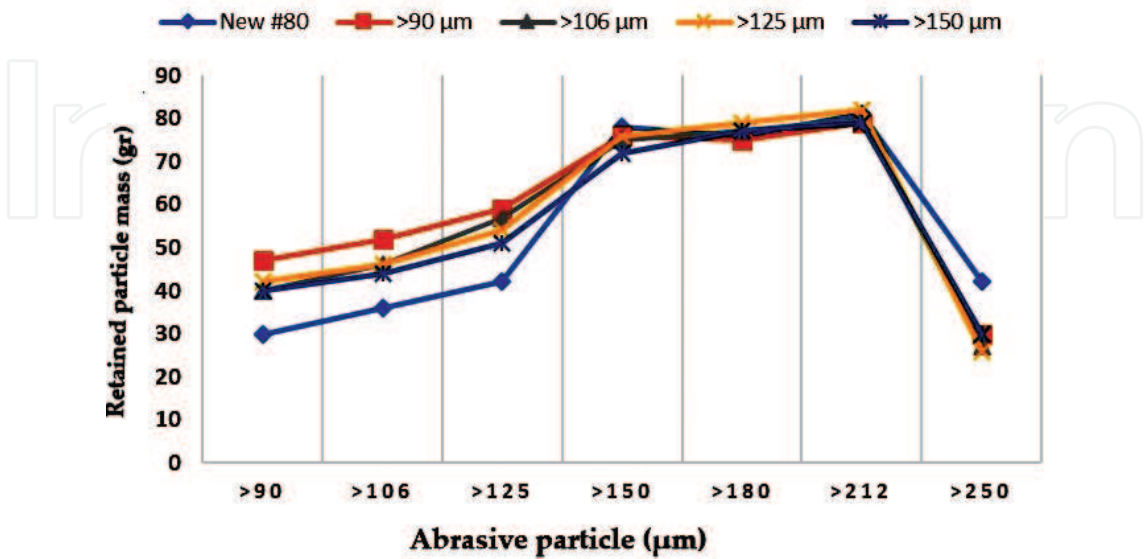


Figure 3. Retained particle mass versus recycled particle size after mixing process.

4.2. Cutting performance and cutting quality of recycled abrasives

4.2.1. Experimental setup

Figure 4 shows the experiment setup for comparison of the cutting performance (or the maximum depth of cut) between the new and recycled abrasives. The workpiece in this experiment is described on **Figure 5**, and its material is SUS304. In the experiment, four samples of recycled abrasives (with particles larger than 90, 106, 125, and 150 μm) and a sample of new Supreme garnet #80 are used for the test. Each abrasive sample is tested with five cuts and with two replications. The AWJ cutting parameters used in the experiment include the water pressure of 350 MPa, the abrasive mass flow rate of 540 g/min, the orifice diameter of 0.33 mm, the nozzle diameter of 1.02 mm, and the feed speed of 100, 125, 150, 175, and 200 mm/min.

In order to investigate the effects of the recycled abrasives on the surface roughness, four recycled abrasive samples (as mentioned above) and a new Supreme garnet #80 are tested (with two replications) with the following cutting regime: the workpiece material of SUS304,



Figure 4. Experimental setup for determination of maximum depth of cut.

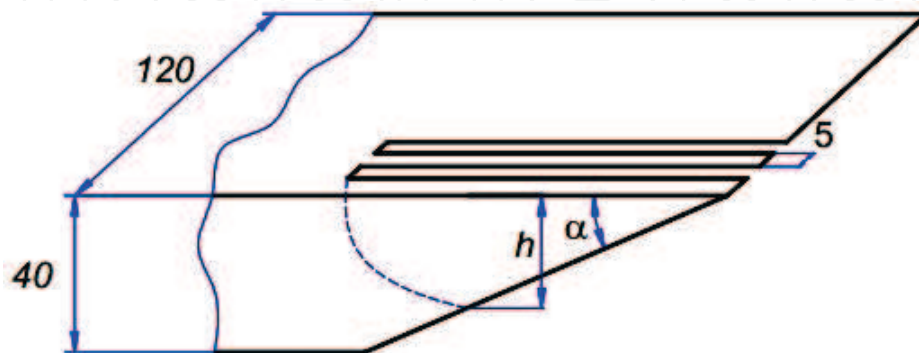


Figure 5. Workpiece used in experiment for determination of maximum depth of cut [20].

the water pressure of 350 MPa, the abrasive mass flow rate of 540 g/min, the feed speed of 125, 150, 175 and 200 mm/min, the focusing tube diameter of 1.02 mm, and the orifice diameter of 0.33 mm.

4.2.2. Results and discussions

Figure 6 shows the cutting performance of the recycled abrasives. It is noticed that the cutting performance of all recycled samples is slightly higher than that of the new Supreme garnet #80. This can be explained that after mixing process, with the new sample, the mass of retained particles with the size $<150\ \mu\text{m}$ is less than that of all recycled samples (**Figure 3**). Consequently, the number of recycled particles involved in the cutting process is higher than that of the new sample. Hence, the removed workpiece volume and therefore the cutting performance grow. It is also found that there is an optimum value of the recycled abrasive size (particle size larger than $90\ \mu\text{m}$) with which the cutting performance is maximum.

To evaluate the influence of recycled abrasives on the cutting quality, the surface roughness (R_a) is measured (**Figure 7**) at six values of the depth from 5 to 30 mm. **Figure 8** describes the average of the surface roughness of three replications of tests. It is detected that the surface roughness of the recycled abrasive is slightly lower than that of the new. The reason is that although the recycled particles are smaller than the new ones, they are sharper. As a result, the influences of the recycled abrasive size and shape on the surface roughness can be considered equivalent.

4.3. Cutting performance and cutting quality of recharged abrasives

4.3.1. Experimental setup

In order to find the optimum particle size of recharged abrasives, four samples of the first recycled abrasives (with the particle size larger than 90, 106, 125, and $150\ \mu\text{m}$) are recharged

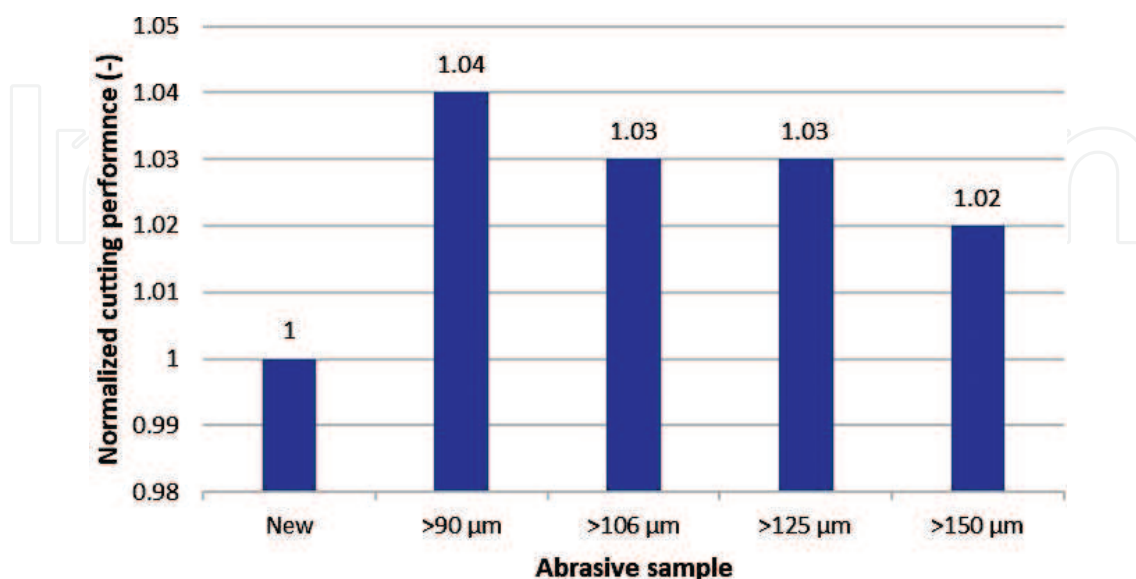


Figure 6. Cutting performance of recycled abrasives.



Figure 7. Measurement of surface roughness.

with the new abrasive (Supreme garnet #80) for getting the same amount of abrasives (100%) (Table 2). To investigate the cutting performances of these recharged samples, experiments with the same setup as that for the cutting performance of the recycled abrasives (Figure 4) are carried out.

To investigate the effects of the recharged abrasives on the cutting performance and cutting quality, four recharged abrasive samples (as mentioned above) and a new Supreme garnet #80 are tested (with two replications). The cutting regime of these experiments consists of the

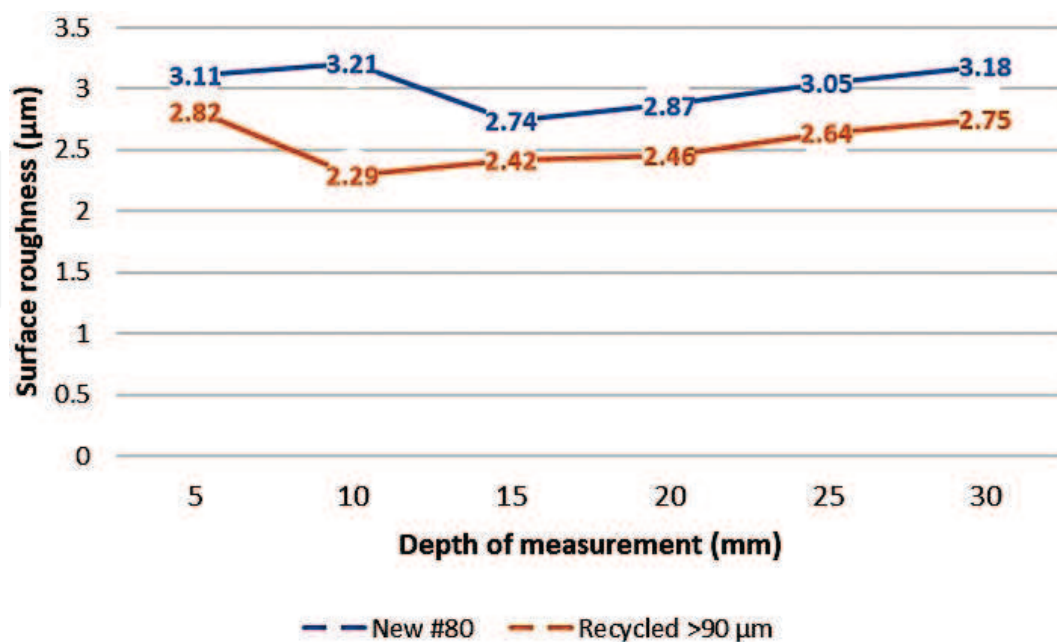


Figure 8. Surface roughness when cutting with recycled abrasives.

Sample	Sieve nominal aperture size (μm)	Reusability (%)	Recharged abrasive (%)
1	150	58.8	41.2
2	125	53.4	46.6
3	106	47.0	53.0
4	90	38.7	61.3

Table 2. Recharging abrasives.

workpiece material of SUS304; the water pressure of 350 MPa; the abrasive mass flow rate of 540 g/min; the feed speed of 125, 150, 175, and 200 mm/min; the focusing tube diameter of 1.02 mm; and the orifice diameter of 0.33 mm.

4.3.2. Results and discussions

Figure 9 presents the cutting performance of the recharged abrasives. It is observed that the cutting performance of all recharged samples is higher than that of the new Supreme garnet #80. The reason of that is the same with recycled samples (see Section 4.2.2): with all recharged samples, the mass of retained particles with the size smaller than 150 μm is higher than that of the new (see Figure 10). Hence, the particle in the recharged samples and then the particle number taking part in the cutting process increase. Consequently, the volume of removed work material growth and therefore the cutting performance increase. It is also detected that the particle size larger than 90 μm is the optimum value with which the cutting performance is maximum.

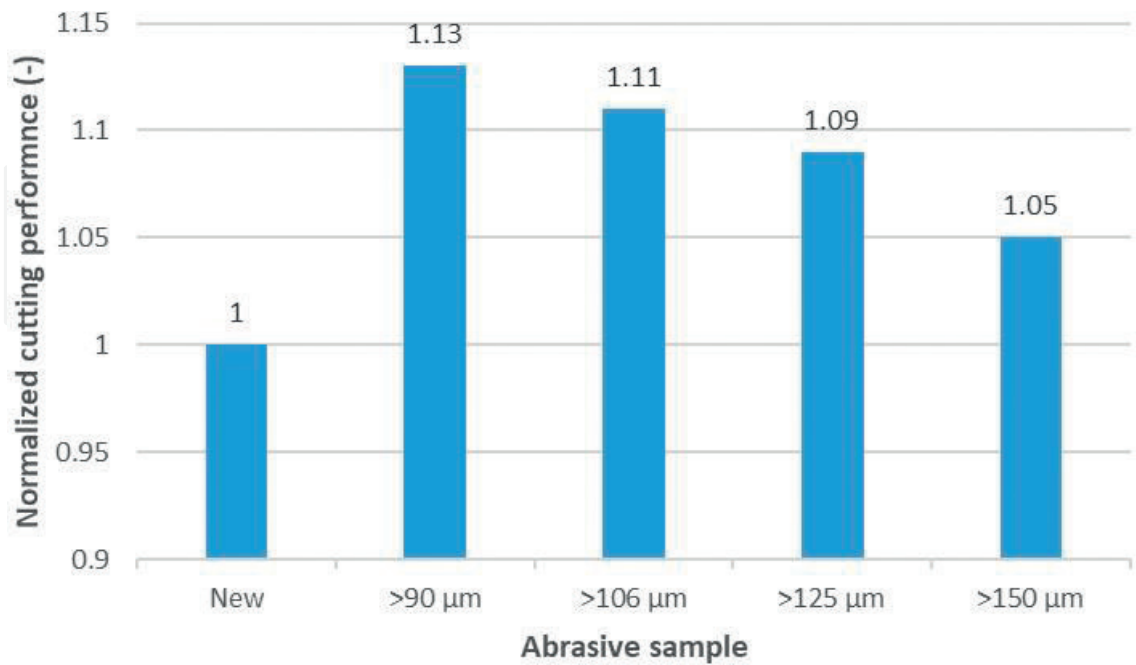


Figure 9. Cutting performance of recharged abrasives.

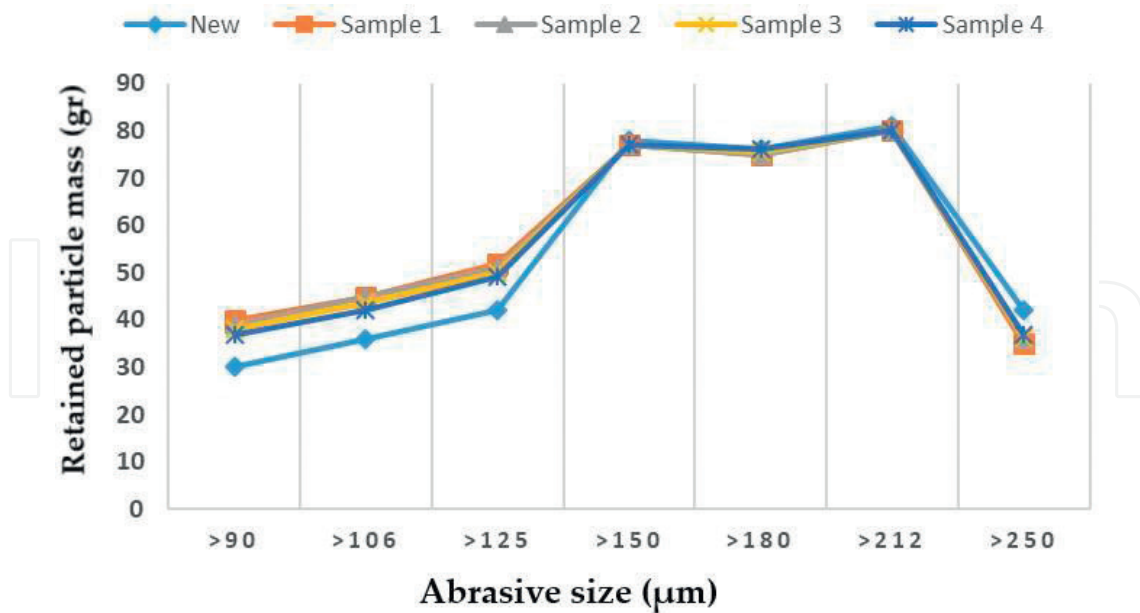


Figure 10. Retained particle mass versus recharged particle size after mixing process.

In order to evaluate the effect of recharged abrasives on the cutting quality, the surface roughness (Ra) is measured at six values of the depth from 5 to 30 mm. **Figure 11** shows the average of the surface roughness of three replications of tests. It is found that the surface roughness when cutting with recharged abrasive is slightly lower than that when cutting with new Supreme garnet #80. As it was explained above (in Section 4.2.2), in spite of the fact that the recharged particles are smaller than the new ones, they are sharper. Hence, the effects of the recharged abrasive size and shape on the surface roughness are considered equivalent.

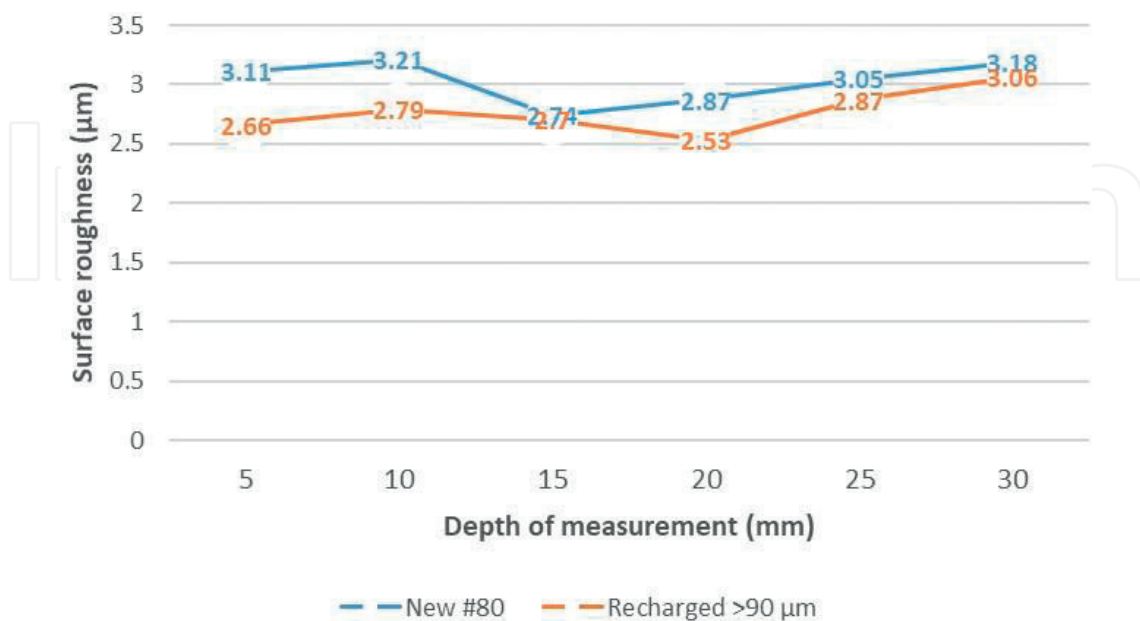


Figure 11. Surface roughness when cutting with recharged abrasives.

5. Conclusions

In this chapter, the investigation of recycling and recharging of Supreme garnet, including the reusability of the abrasive, the cutting performance, and the cutting quality of the recycled and recharged abrasives, has been carried out. Several conclusions can be obtained from the investigation as follows:

- The reusability of Supreme garnet is higher than that of GMA garnet. For example, with the particle size of $>90\text{ }\mu\text{m}$, the reusability of Supreme garnet is 58.86%, while it is only 53.64% for GMA garnet.
- The cutting performance of recycled and recharged Supreme abrasives is slightly higher than that of the new Supreme garnet #80.
- The optimum particle size for the cutting performance is larger than $90\text{ }\mu\text{m}$ for both the recycling and the recharging.

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