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ARCHIVES
of
FOUNDRY ENGINEERING

10.24425/afe.2019.129617

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (2299-2944)
Volume 19
Issue 3/2019

94 – 98

16/3

The Use of Abrasive Waterjet Cutting to Remove Flash from Castings

D. Bańkowski *, S. Spadło
Department of Metal Science and Manufacturing Processes, Kielce University of Technology,
ul. Tysiąclecia Państwa Polskiego 7, 25-314 Kielce, Poland:
* Corresponding author. E-mail address: dbankowski@tu.kielce.pl, sspadlo@tu.kielce.pl

Received 11.06.2019; accepted in revised form 22.07.2019

Abstract

This article proposes to use abrasive waterjet cutting (AWJ) for deflashing, deburring and similar finishing operations in casting. The basic requirements concerning the dimensional accuracy and surface texture of cast components are not met if visible surface flaws are detected. The experiments focused on the removal of external flash from elements made of EN-GJL-150 cast iron. The method employed for finishing was abrasive waterjet cutting. The tests were carried out using an APW 2010BB waterjet cutting machine. The form profiles before and after flash removal were determined with a Taylor Hobson PGI 1200 contact profiler. A Nikon AZ100 optical microscope was applied to observe and measure the changes in the flash height and width. The casting surface after finishing was smooth, without characteristic sharp, rough edges that occur in the cutting of objects with a considerable thickness. It should be emphasized that this method does not replace precise cutting operations. Yet, it can be successfully used to finish castings for which lower surface quality is required. An undoubted advantage of waterjet cutting is no effect of high temperature as is the case with plasma, laser or conventional cutting. This process is also easy to automate; one tool is needed to perform different finishing operations in order to obtain the desired dimensions, both internal and external.

Keywords: Surface treatment, Quality management, Automation and robotics in foundry, Abrasive water jet cutting, Finished castings

1. Introduction

The casting process involves filling a mold with liquid metal using gravity, centrifugal forces or pressure. Then, the metal is cooled to allow crystallization. Finally, the solidified part is removed from the mold for further cooling and finishing [1, 2]. The finished product undergoes quality control, during which it is inspected for dimensional accuracy, structural integrity and surface finish. Depending on the type of casting and the batch size, quality control can be carried out manually or automatically with or without specialist testing equipment. The most common methods employed by foundries are visual inspection and radiographic testing. The latter involves exposing the cast element to radiation and then interpreting the radiographic image using specialist computer software. If imperfections are detected further examination is required. The least popular methods applied to inspect castings include chemical spectral analysis. Thus, whatever quality control system is used, it provides information whether to accept or reject a casting; in other words, whether the product can leave the factory.

The finishing of raw castings requires removing all the excess material and achieving the desired surface texture. The number and type of finishing operations are dependent on the casting process. The operations include:

- degating,
- deflashing,
- desanding, i.e. removing residual mold and core sand,
- deburring,
- improving surface finish,

- preparing the cast product for mechanical finishing, heat treatment or painting; if a product is cast in parts, joining them [3].

Deflashing and deburring are the primary finishing processes used for castings [4]. Burrs and other surface flaws are generally found where the mold and core parts were in contact with the casting; they also include vent hole burrs and other sharp edges and protrusions produced on a product surface during the casting process. Such imperfections are usually removed using grinding wheels or grinding stones. Grinding wheels are applied to finish larger surface areas, while grinding stones are to employed for detail finishing [5-6].

Flash, burrs and other small surface defects on cast products can also be removed using mass finishing methods, the most common of which are tumble and vibratory finishing [7, 8]. Castings are placed in a special drum or vibratory chamber together with abrasive pellets of media, differing in shape and size. The required surface finish is achieved as a result of the abrasive friction between the workpiece and the media [9]. Pyramid-shaped abrasive media are some of the most common. Tumbling and vibratory finishing may also require the presence of water and a lubricant/an agent [10]. The abrasive strength of media must be suitable for the material and size of the cast product being finished [11].

Mass finishing operations are difficult to automate as flash and burrs may have a variety of shapes; besides, casting imperfections need to be removed in a simple and quick way [12]. Automated grinding machines are becoming increasingly common in series production applications. Raw castings placed inside such a machine do not require additional finishing including manual grinding [13].

Automation of casting finishing processes may also involve using the following techniques:

- hammering; some cast components are produced with a predetermined number of surface imperfections (burrs and flash) located in easy-to-predict and easy-to-access places; when the batch size is large, it is cost-effective to install hammering machines for fast and easy removal of typical casting surface imperfections;
- milling; with the advancements in electronically controlled machine tools, it has become much easier to develop complex programs for CNC machining operations to deal with small-batch and one-of-a-kind items [14, 15].

This article proposes to use abrasive waterjet cutting to remove flash, burrs and other dimensional irregularities of raw castings.

2. Abrasive waterjet cutting

Abrasive waterjet (AWJ) cutting is one of the manufacturing processes providing finished products characterized by low surface roughness [16]. Waterjet cutting is an example of unconventional machining, as are electrical discharge machining, microwelding, electrochemical machining and laser cutting [17]. Conventional machining methods include milling, drilling, turning and grinding [18].

Abrasive waterjet (AWJ) cutting is a universal process used for cutting a variety of materials differing in physical characteristics, ranging from wood and minerals to metals and metal alloys. It is also suitable for composite materials [19]. Another advantage of AWJ cutting is the possibility to cut elements with different thicknesses, which is achieved mainly by applying appropriate cutting speeds and pressures. The abrasive particles in the stream of water cause erosion of the material, which involves removal of micro particles from the workpiece along the cut line [20]. The factors contributing to increased use of waterjet cutting for difficult-to-cut materials are [21, 22]:

- no thermal effects on the material being cut,
- occurrence of low pressure forces during the machining process,
- negligible impact of the process on the natural environment and human health,
- no need to use specialist equipment,
- the possibility to achieve a high quality of cut for virtually any material.

The above benefits make abrasive waterjet cutting a universal technology with an increasingly wider range of applications.

Abrasive waterjet cutting is a method for shaping materials using a high-pressure, high-velocity, small-diameter stream of water containing abrasive particles. Generally, natural abrasives, e.g., garnet, are used in this process. The erosion of the material cut is dependent on the hydraulic energy of the stream of water and the kinetic energy of the abrasive grains in the stream. As the initial impact force of the waterjet is very high, higher than the impact strength of the workpiece, microcracks form, with the material gradually undergoing mechanical erosion [20].

The phenomenon causes the material to deform plastically; then, cracks and other surface flaws occur in the material. The surface texture is generated in the near-surface layer mainly as a result of microcutting. The cut microgeometry is largely dependent on the abrasive grain size. Once the stream of water penetrates into the material being cut, its energy decreases and the surface texture generation is affected by abrasive wear, i.e., mechanical erosion [23] and surface irregularities occur.

The surface texture generated through abrasive waterjet cutting using properly selected parameters is characterized by a high quality of cut [24]. The machining parameters affecting the geometry of the cutting gap include:

- water pressure,
- feed rate,
- type, size and amount of abrasive particles,
- distance from the nozzle to the workpiece,
- workpiece material and thickness.

The machining parameters need to be properly selected to allow penetration of the abrasive waterjet into the material to a desired depth. Basically, surface waviness can be minimized by optimizing the water pressure, the feed rate, the nozzle type and size and the stream diameter [25].

3. Experiment

The specimens tested were made of EN-GJL-150 cast iron (Fig. 1). This material is used for machinery castings with no special requirements in terms of strength, fracture tightness or wear resistance. Typical applications of the material include cases, racks, pulleys, boxes, machine parts, machine tool elements. EN-JL1020 (EN-GJL-150) cast iron has tensile strength, R_m, of 150-250 MPa.

The experiments were carried out using an APW 2010BB waterjet machine with a 18.5 kW pump, able to produce a waterjet stream with a maximum working pressure of 300 MPa. This machine has a 2000x1000 mm table. The other main parameters are as follows:

- abrasive: garnet # 80,
- waterjet nozzle: ø 0.30 mm,
- focusing tube: ø 1.02 mm and $l = 76.2$ mm.
- stand-off distance (distance between focusing tube and the workpiece): 2 mm.
- water pressure: 280 MPa
- cutting speed: 10, 30 and 50 mm/min.

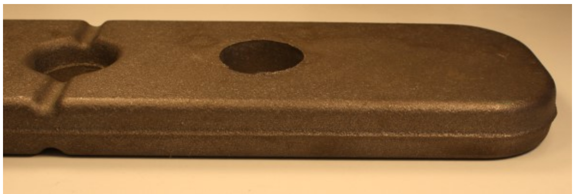

Fig. 1. Unfinished casting

Figure 2 shows a photograph of a casting taken with a Nikon AZ100 optical microscope (OM) at 10x magnification. The photo shows the height and width of the flash measured relative to the flat surface.

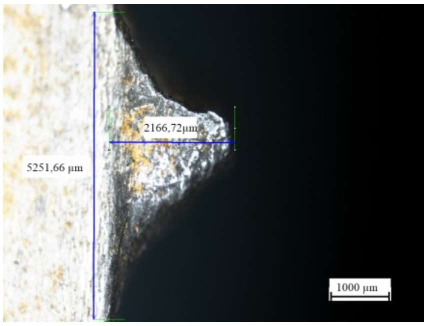

Fig. 2. Example of flash to be removed

4. Results and discussion

The purpose of the experiments was to apply abrasive waterjet cutting to remove flash being a result of material leakage between two surfaces of a casting mold. Castings made of EN-GJL-150 cast iron were used in the study. The castings considered in this study are traditionally used as weights in workout equipment, e.g., Atlas.

In many cases, castings do not need high-quality surface finish. Frequently, only deflashing and deburring are required. Sometimes, it is also necessary to clean the casting surface. Abrasive waterjet cutting seems to be a perfect solution for such purposes.

This method has an undeniable advantage over the conventional deflashing methods because only one machine is needed to perform different finishing operations on different types of casting. The process requires introducing the item geometry into the machine memory, i.e., the line of cut. It should be emphasized that one position can be used to machine external and internal surfaces as well as surfaces with complex geometries. Manual finishing would be a relatively costly time-consuming process.

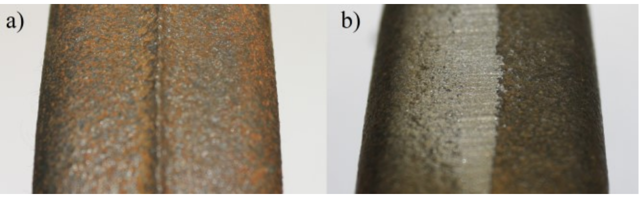

Fig. 3. Castings a) before and b) after deflashing with an abrasive waterjet machine

A Taylor Hobson PGI 1200 contact profiler was used to determine the form profiles of the tooling parting line. The measurements were performed before and after flash removal during AWJ cutting at three cutting speeds (50, 30 and 10 mm/min). The results are summarized in Table 1. Examples of flash profiles are provided in Figure 4.

Table 1.
Results of flash measurements

	max height, μm	height, μm (arithmetic mean)	width, μm
before cutting			
	1443.98	1431.89	1235.17
after cutting			
V= 50mm/min	439.38	431.64	2898.43
V= 30mm/min	222.00	218.04	6391.05
V= 10mm/min	165.66	161.10	8217.14

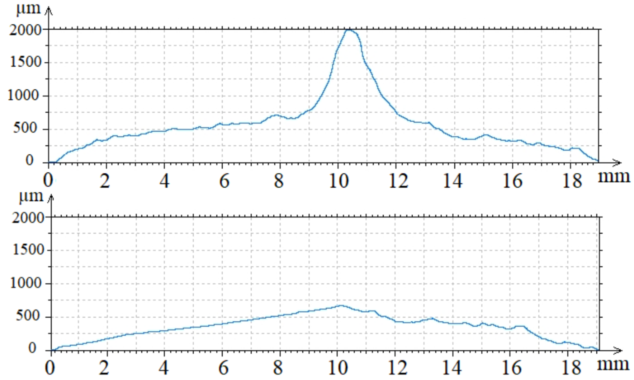

Fig. 4. Surface profile: a) before and b) after flash removal through AWJ cutting at v = 50 mm/min.

AWJ cutting seems to be a well-suited method for deflashing and deburring in the case of castings with low surface quality requirements.

From the measurement results obtained with a contact profiler (Table 1), it is evident that the arithmetic mean of the flash height before removal was about 1400 µm, while that after removal using abrasive waterjet cutting ranged from approx. 430 to 160 µm.

The height of the residue depended on the waterjet speed. The lower the cutting speed, the better the surface quality, and this is related to the cutting process kinematics.

At a cutting speed of 10 mm/min, the flash height decreased from approx. 1440 µm to approx. 165 µm. At higher speeds of abrasive waterjet cutting, deflashing was less effective. The use of a cutting speed of 30 mm/min resulted in the removal of about 220 µm of flash. When a cutting speed of 50 mm/min was tested, about 440 µm of flash was removed.

The decrease in the height of the flash was associated with an increase in the width of the surface erosion. At the lowest cutting speed, i.e., 10 mm/min, the erosion width was approx. 8 mm. At 30 mm/min, it was approximately 6 mm. At the highest cutting speed (50 mm/min), the width reached approx. 3 mm.

It should be noted that the water stream does not penetrate into the material along a straight line. Figure 5 shows the specimen surface after AWJ cutting. After the process, the surface had an anisotropic structure; there were visible marks left by the process. Lines L1 and L2 indicate the regions of higher and lower quality of cut, respectively. The deeper the penetration or the higher the cutting speed, the lower the quality of the cutting process.

Fig. 5. Surface after AWJ cutting

It can be concluded that lower cutting speeds should be used to increase the dimensional accuracy and surface quality of machined castings [26]. Also, in the case of AWJ machines operating in more than 3 axes [27], even a small-angle inclination of the cutter will reduce the deflection of the stream. This will prevent occurrence of areas characterized by lower surface quality.

Figures 6 and 7 show OM images of the surfaces before and after AWJ cutting, respectively.

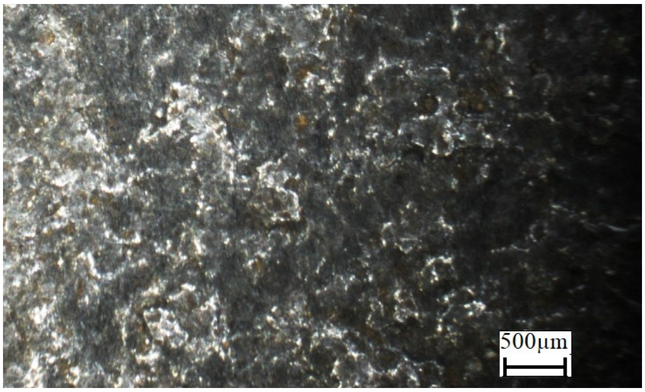

Fig.6. OM image of the surface before AWJ cutting. -*x10.*

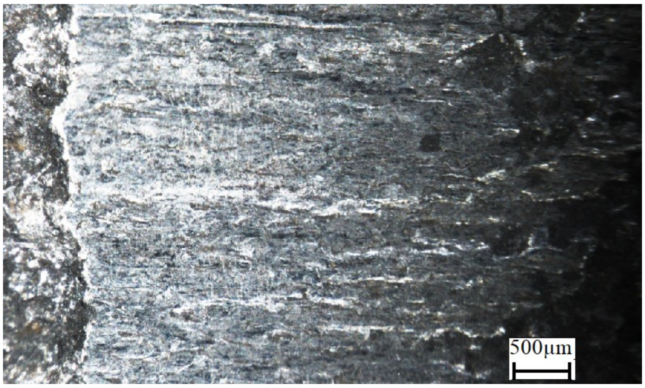

Fig.7. OM image of the surface after AWJ cutting, *x10*

5. Conclusions

The experimental results show that AWJ cutting can be used to remove all or most of molding flash and burrs and similar casting surface flaws.

AWJ cutting can replace conventional finishing operations only when raw castings do not require precise machining.

The highest efficiency of AWJ cutting used for deflashing was observed at the lowest cutting speeds. At higher speeds of abrasive waterjet cutting, deflashing was less effective.

After AWJ cutting, the surface had anisotropic structure; there were visible marks left by the process.

The best effects can be obtained when the cutter is slightly inclined.

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