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Deburring and edge finishing of aluminum alloys: A review

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Abstract: The burr formation is one of the most common and undesirable phenomenon occurring in machining operations, which reduces assembly and machined part quality. To remove the burrs, a costly and non-value-added process known as deburring is required for post-processing and edge finishing. A basic overview of burr formation and removal is presented in this paper. Due to vast applications of aluminum alloys in many industrial sectors, such as automotive and aerospace industries, this paper also describes the most highly used deburring and edge finishing on aluminum machined parts. The main advantages, disadvantages, limitations, part quality and precision of these operations are presented. This can be beneficial for an adequate selection of deburring methods, cost reduction and production rate improvement

Keywords: Aluminum alloy, Burr, Deburring, Edge finishing

1. Introduction

Burr formation is a major concern in the surface and edge finishing of work parts, which eventually leads to reduced work parts resistance, tool life and productivity rate. Therefore, it is necessary to limit the burr formation; otherwise the use of secondary operations known as deburring becomes essential. Throughout intensive research works during the last decades, the mechanisms of burr formation are very well understood and comprehensive and integrated strategies for burr prevention and minimization were introduced. However, particular attention should to be paid to deburring operations, which are in fact expensive, time consuming, non-productive and non-value added processes.

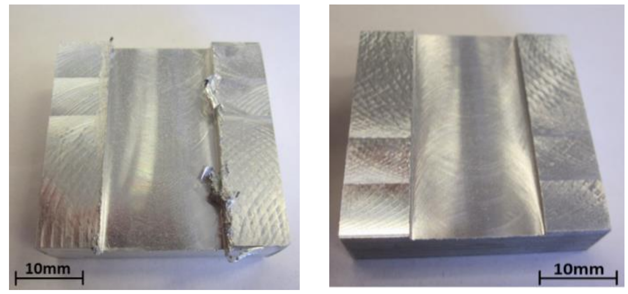
According to [1], the main critical factors on deburring complexity are burr location, length and number of edges to be deburred and burr size. In fact, the secondary finishing operations are difficult to automate, therefore they may become a bottleneck in production lines [2]. There are more than 100 deburring methods [3], therefore proper understanding of the basic mechanisms of burr formation and optimal cutting parameters is strongly suggested for an adequate selection of deburring method and minimizing the non-desirable expenses. This subject becomes even more difficult when dealing with aluminum components.

The burr sizes in aluminum work parts vary when changing the machining mode and cutting conditions (see Figures 1-2). The burrs in aluminum works parts can be excessively large and irregular (see Figure 1a), or small, even not visible for naked eyes (see Figure 1b), if proper conditions are used. The major machinability assets related to aluminum alloy include tool life, chip characteristics, chip disposal, surface finish and burr formation, which might be also affected after deburring operations.

The major side effects of deburring methods on aluminum work parts may appear on dimensions, tensile residual stress, smut, discoloration, surface passivation and generation of new burrs. In addition, the rate at which the work parts are rejected due to presence of burrs is also amongst essential criteria for deburring selection. Therefore, acquiring a solid knowledge on deburring methods and the links between them and burr size is strongly recommended. In this article, the most highly used industrial deburring methods in aluminum work parts will be presented. This can be beneficial for an adequate selection of deburring methods, cost reduction and production rate improvement.

2. Overview of burr formation

As defined in [4], the edges on a workpiece is called burr (see Figure 3), if they have an overhang greater than zero.



(a) (b)

Figure 1.Slot milled 6061-T6 aluminum machined part with (a) large burrs (b) acceptable burr size [5]

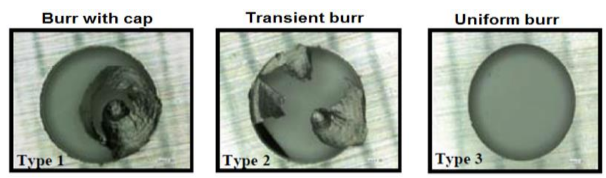


Figure 2. Exit burrs when drilling 6061-T6 aluminum work parts [6]

As can be seen in Figure 3, to better describe the burr, a new term called "burr value" was defined in [7]. It contains the burr root thickness (b_r), burr height (b_h), burr thickness (b_t) and burr root radius (r_f).The burr height and thickness are used to determine the tool replacement and schedule and also burr removal difficulties [8]. However the longitudinal profile of the burr is not highly informative in most cases, as it is rarely used to describe burrs [5; 9].

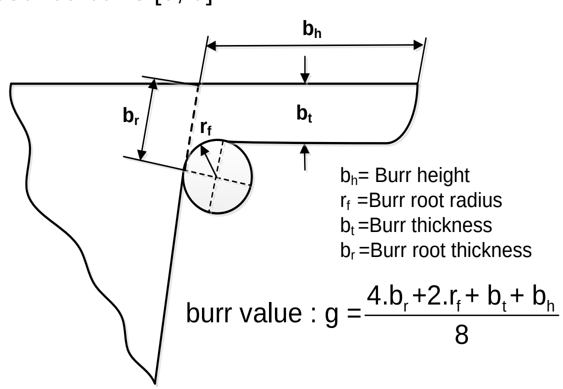


Figure 3. Measurement values of burr (*adapted from* [7])

3. Deburring operations

Burrs have always been a serious concern in the surface and edge finishing of machined parts. According to [10], achieving an excellent edge quality when using deburring processes is often difficult. To better select the deburring processes, several classifications were proposed in [3; 7; 11]. The most complete one was made in [3], encompassing all deburring methods, from manual deburring to high technology finishing systems using CNC and industrial robots. Gillespie [3] has identified 122 deburring and edge finishing processes which can be classified under following categories:

1. Mechanical deburring processes;
2. Thermal deburring processes;
3. Chemical deburring processes;
4. Electrical deburring processes;

According to Table 1, the most frequently used deburring processes in manufacturing industries have been introduced by Gillespie [3]. Most of deburring tools and processes are developed for materials with specific geometries. Therefore, correct selection of deburring process is essential. The first approach for deburring process selection was proposed in [7]. Later, a software tool was developed in [12] for similar purpose. In this tool, burr shape, surface roughness, workpiece properties, weight and volume were used to create the database. Thilow [13] also introduced an industrial system for similar purpose. As described earlier, all reported deburring processes have certain levels of side effects on work parts. This article does not, however, try to present the main advantages, disadvantages and restrictions related to deburring processes. Furthermore, due to limited space in this article, the main highly used deburring methods on aluminum work parts will be presented in the following sections.

Table 1.The most frequently used deburring processes [3]

No.	Deburring process	No.	Deburring process
1	Manual deburring	6	Barrel deburring
2	Brush deburring	7	Centrifugal barrel finishing
3	Bonded abrasive deburring	8	Robotic deburring
4	Abrasive jet deburring	9	Electro chemical deburring
5	NC/CNC deburring	10	Vibratory finishing

Mechanical deburring processes

During mechanical deburring processes, the burrs are reduced or removed by mechanical abrasion. Various mechanical deburring systems were developed so far [14; 15]. The overview of most highly used mechanical deburring methods for aluminum alloys will be presented in the following sections.

Manual deburring

Manual deburring is still known as the most widely used operation for many reasons, including extreme flexibility, low cost and lack of technology needed. According to [3], manual deburring is associated with wasting of time and asset, fatigue, frustration, etc. Moreover, in most of industrial sectors, manual deburring is implemented in dry conditions by non-qualified operators. This consequently increases the waste rate and delay in production lines.

Abrasive blasting

Abrasive blasting is known as one the subcomponents of the blast finishing which require less labor than other deburring methods. Blasting equipment is designed to provide a concentrated stream that impacts specific edges.

The main types of abrasive blasting deburring include:

1. Conventional dry blasting
2. Conventional wet blasting
3. Microblasting

Conventional dry blasting commonly use air blasting and centrifugal wheel (airless) blasting. The work parts coated with grease or oil can not be easily cleaned or finished by dry blasting. Thus the degreasing and drying should be performed prior to blasting. The use of dry blasting for automatic deburring is examined in [16].

Wet blasting or vapor blasting uses the media particle in slurry form and does not require the use of dust collector or ventilation equipments. This method also provides a good surface finish. The main operational variables involved in wet blasting are velocity and density of blast slurry, abrasive type and size, angle of attach, blast nozzle size, type and distance from work part and desired work part quality level and production rate.

Microblasting, also known as abrasive-jet machining (AJM) is used for removing material from work parts using a high-speed stream of media particles through a nozzle by gas. This process is used for cutting, deburring, clearing and edge finishing of wide range of materials, including aluminum alloys, with very low level of waste rate. The process is capable of removing burrs from the base without forming radius at the part edges. To this end, the parts should be securely fastened during deburring process. Many sides of the work part can be deburred by a single orientation of the abrasive jet. This method is recommended for hard, brittle and miniature materials. This deburring method is fast, but usually only one piece can be deburred at a time. Furthermore, the consumed energy level is relatively low as compared to other methods. As shown in Table 2, the relative cutting (drilling) action on various materials, with higher index numbers indicates greater efficiency. According to Table 2, the drilling efficiency of 2024-T4 aluminum alloys is larger than that of glass and stainless steel AISI304 [3].

Table 2. Relative cutting action of various materials (*adapted from* [3])

Material	Cutting index
Glass	0.6
Aluminum alloy 2024-T4	1.6
Stainless steel AISI304	0.9
Cold rolled steel	1.0
Ferrite	3.0
Neoprene	0.05
Al_2O_3	0.4

Bonded-abrasive deburring

Bonded abrasive deburring or sanding is a versatile deburring technique which can be applied when heavy stock removal is intended. This method performs well in manual and automated operations that are used for deburring and surface smoothing. Many types of bonded abrasives are available (see Figure 4) for dry and lubricated deburring of aluminum alloys and metals work parts. According to [3], three dimensional abrasives products that successfully removed burrs from drilled holes in aluminum work parts did not show enough strength to remove burrs on drilled holes in stainless steels. The main benefits of bonded-abrasive deburring are low cost; large variety of models and great adaptability to manual or automatic equipment. On the other hand, the main disadvantages of this method include short life time, generation of dust emission and new burrs, significant effects on residual stress and surface quality and lack of access to certain sides of the work part.

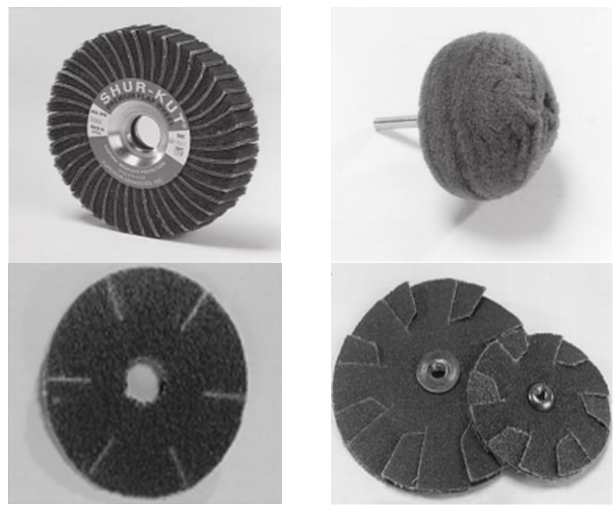


Figure 4. Bonded abrasive slotted tool for deburring (*adapted from* [3])

Brush deburring

The power-driven brush tools have wide range of applications in deburring, cleaning, descaling, polishing, edge blending and texturizing of the metal work parts. The brush deburring (see Figure 5) is considered as a fast, safe, simple, relatively inexpensive, and flexible deburring method, which could be also adaptable to manual or automatic equipment with little operator interference. The rotary action in brushing allows a great variety of driving motor and fixtures to be employed.

The brush deburring involves several environmental, health and safety considerations, including particle and dust emission when using dry sanding of metal and plastic parts. The generation of new burr, new changes on the work part size, fatigue life and residual stress are the main disadvantages and side effects of brush deburring. As described in [3; 17], brush deburring method is widely used for deburring of aluminum work parts, such as cylinder heads (see Figure 7).

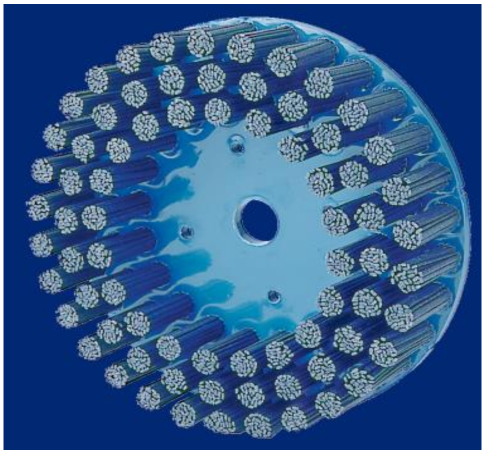
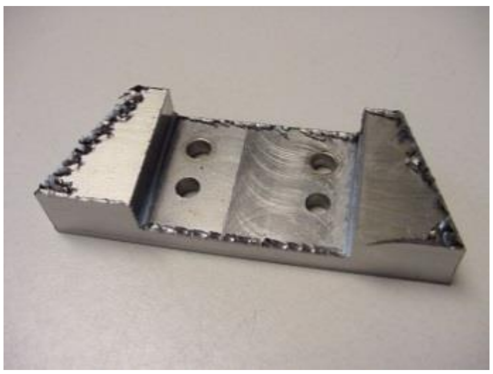
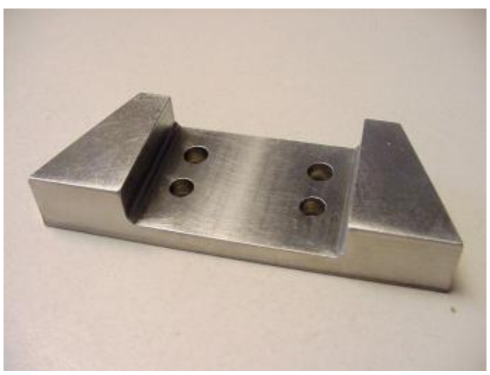


Figure 5. Deburring and edge finishing brush [4]



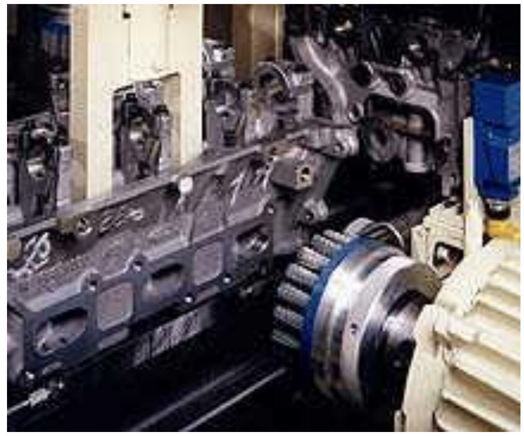
(a) Before deburring



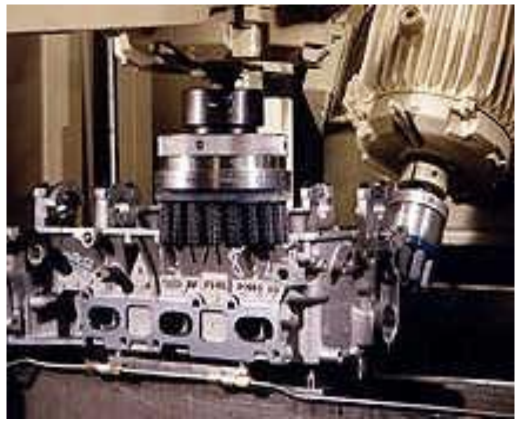
(b) After deburring

Figure 6. Burr edges before and after deburring in 6061-T6 aluminum machined parts [18]

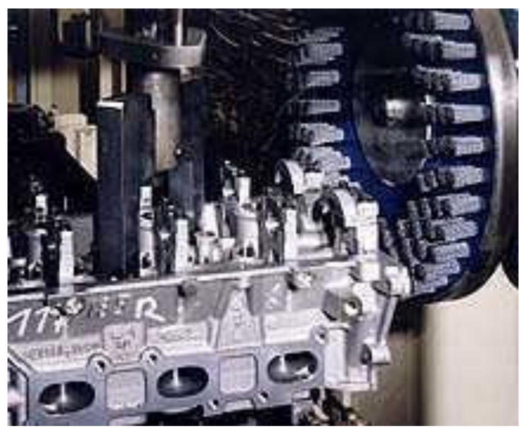
The main process variables involved in brush deburring include, brush style, brush design and materials, face width, coolant, brush rotational speed, burr size, burr location and work part material.



(a)



(b)



(c)

Figure 7. Brush deburring of aluminum cylinder head with various brushing tools [17]

Manual metal cutting/deburring machines

Manual metal cutting/deburring machines can be classified into end-finishing, single purpose and multiple-purposes machines. These machines have been widely used for deburring, brushing, grinding, polishing and buffing of aluminum alloys [3]. A deburring tool with a hemi-spherical cutting head mounted on a pivot shaft was constructed to remove the burrs in intersecting holes of aluminum alloys [19]. Figure 8 shows the drilling edges in 6061-T6 aluminum specimens before and after deburring process. It is exhibited that the burr formation on the exit side of a drilled hole is influenced by exit angle of the burr edge. Kim *et al.* [20] developed a drilling tool capable of deburring. This tool incorporates a deburring cutter which is mounted on a cantilever located within a cavity in the shank of the drill. The experimental verifications conducted on aluminum alloys have shown satisfactory results. Avila [15] described an Orbitool deburring (see Figure 10), capable to create a chamfer on the edge of cross-drilled hole intersections, and removing the burrs, while causing no damage to the surfaces of the hole. He verified his device using experimental works on 6061-T6 aluminum components (see Figure 11) and concluded that this device can be used as an alternative to abrasive brush deburring.

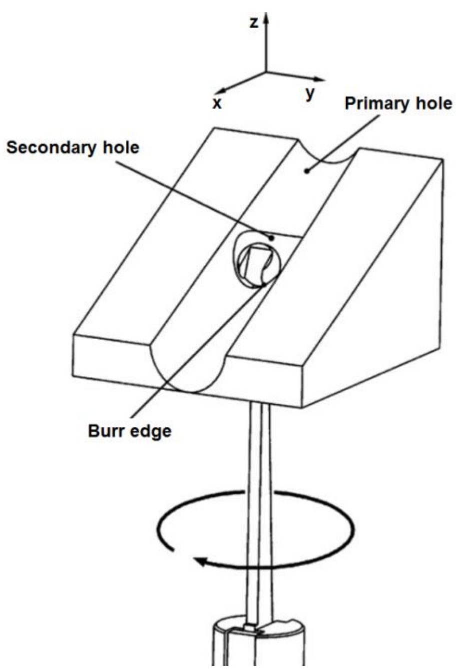


Figure 8. New deburring tool proposed by [19]

As can be seen in Figure 12,a new method for deburring intersecting holes was also proposed by Lee and Ko [21]. This is a deburring tool applied in the high speed deburring of intersecting holes, not flat surfaces. There are two cutting edges on the tool which are supplied by coolant or air. No spring has been used in the tool. This allows high flexibility of the tool by controlling the air or coolant pressure.

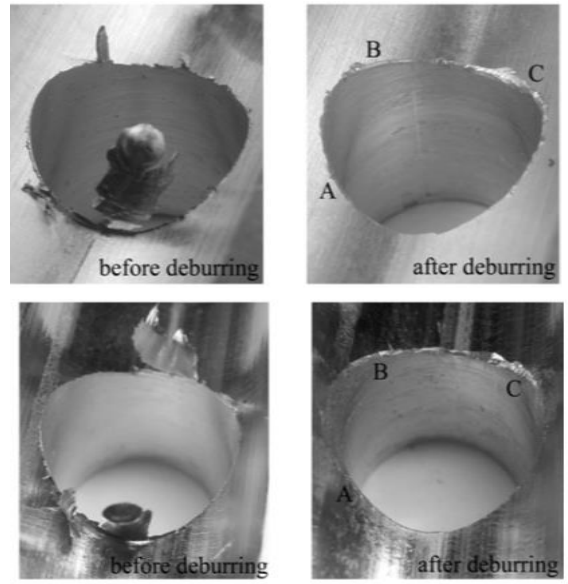


Figure 9. Drilling edges before and after deburring in 6061-T6 aluminum specimens [19]

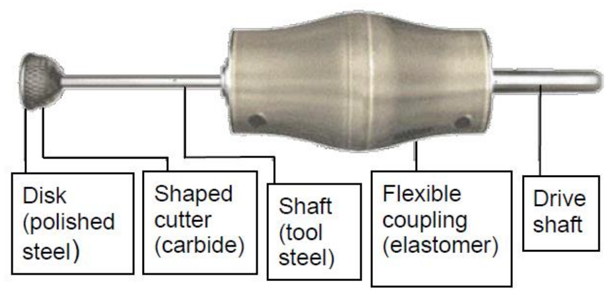


Figure 10. **The Orbitool and its components [15]**

NC/CNC machining centers

Due to growing demands on higher production rate, improved quality and less labour and production cost, particular interest has been paid to use of NC/CNC machines for precise deburring and chamfering of holes, flat and curved surfaces. The NC/CNC machines can brush the machined parts by simply attaching the brushing tools (miniature or large scales) in a tool holder. It also allows the machine to change the tooling conditions and begins the cutting operations and simultaneously taking the advantage of over 1000 standard cutting tools, thus providing great flexibility. Other benefits of NC/CNC machines include prevention of repetitive motions in hand deburring, and lost time due to work-related injuries which may lead to a major cost saving in production line [3]. When using NC/CNC machines, it is also possible to pick up a movable water jet nozzle and traverse it around the machined part edges for deburring and edge finishing (see Figure 13). However this method can be used on the aluminum work parts which require reasonable but not complete burr removal [4].

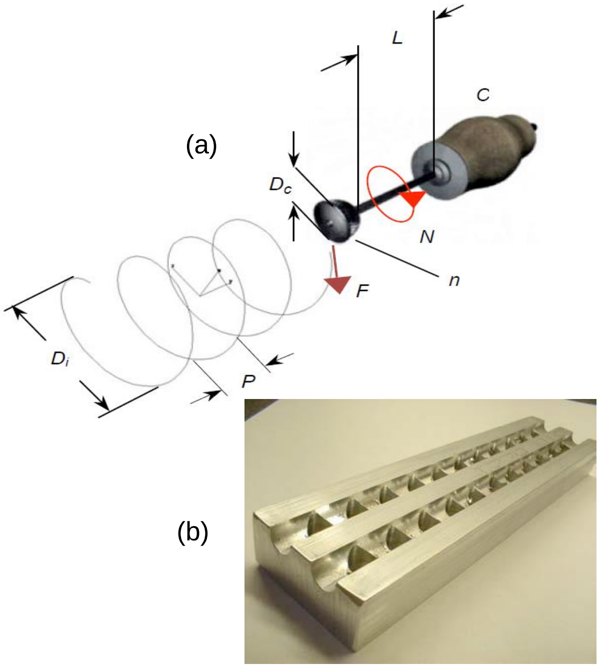


Figure 11. (a)The Orbitool deburring process (b) 6061-T6 aluminum test samples [15]

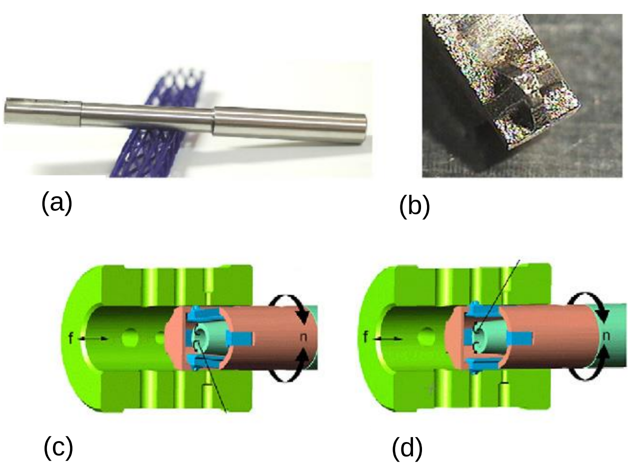


Figure 12. Beier deburring tool: (a) Beier tool, (b) Cutting edge of the Beier tool, (c) inner surface and (d) intersecting hole [21]

A polishing/deburring machine is developed in [22], consisting of two subsystems (see Figure 14). The first subsystem is a five-axis machine for tool/part motion control and the second subsystem is a compliant toolhead for tool force control. Both subsystems are designed based on the tripod principle. According to experimental results, this machine could perfectly perform automated polishing/deburring on aluminum work parts. In addition, the use of NC/CNC machines may not produce high quality cast or forged surfaces. The main concerns when using NC/CNC machines are comprehensively presented in [3].

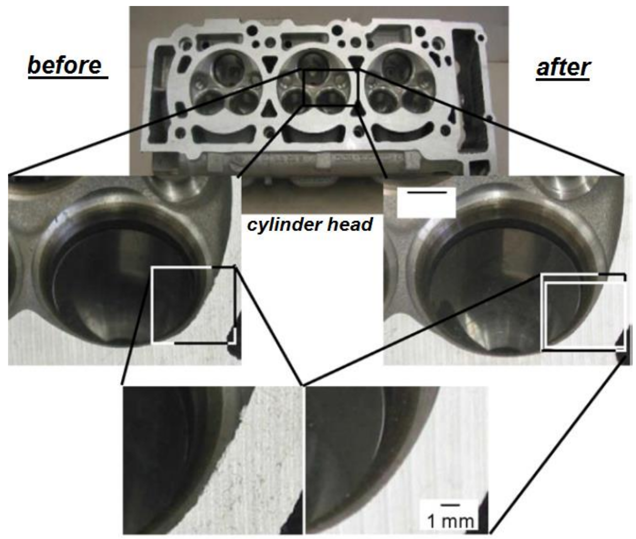


Figure 13. High pressure water jet deburring of aluminum cylinder heads [4]

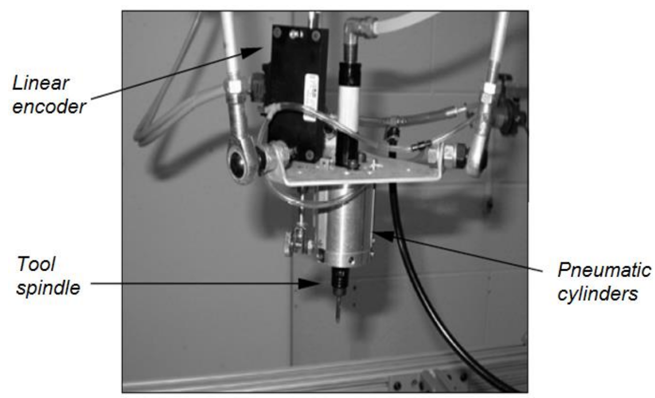


Figure 14. Deburring toolhead adaptable on a CNC machine center spindle [22]

Robotic deburring

Robots can operate with no time limit (three shifts a day), reproduce the same motions accurately; can process workpieces faster than humans, they can use heavier, higher-powered tools for faster finishing, they can work in hazardous, noisy and ergonomically unsuitable situations for humans (see Figure 15). Robotic deburring is used to reduce the work load and guarantee an adequate workpiece quality level. Robotic applications fall into three general areas (1) simple-shape deburring and chamfering, (2) contouring and (3) sensor-controlled countering. A framework for robotic deburring applications in various industrial sectors was proposed in [23]. The use of robots for deburring operation was reported in [24; 25]. Robotic deburring of gearbox casting made from aluminum alloys is presented in [26]. In [27], an on-line industrial robot path generation method has been developed and implemented to generate robot paths for deburring cast aluminum wheels (see Figure 16). This method could automatically generate 6 degree of freedom (DOF) tool paths for an accurate and efficient deburring process.

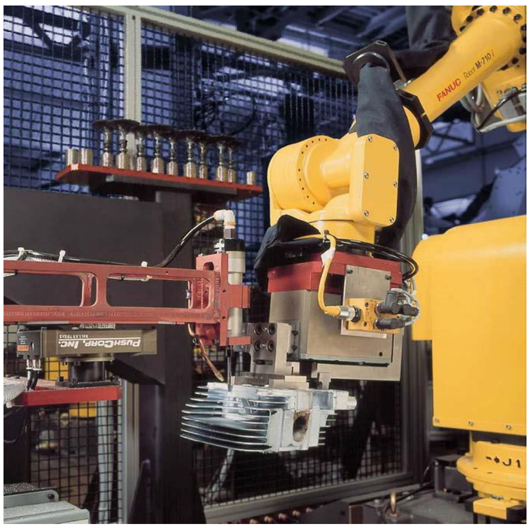


Figure 15. Robot deburring on an aluminum motorcycle cylinder head [26]

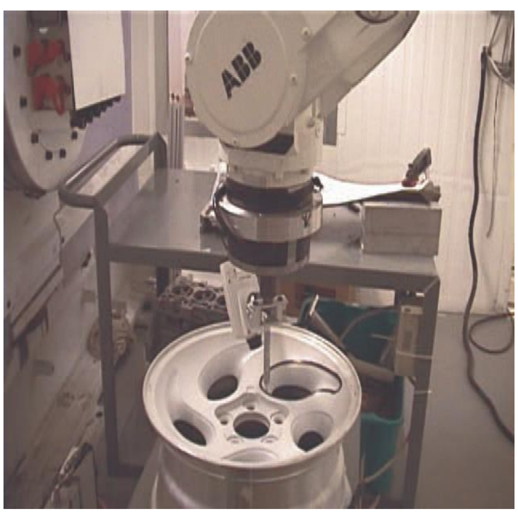


Figure 16. A deburred and polished aluminum wheel [27]

Kazerooni [28] presented robotic deburring using tungsten cemented carbide rotary files He introduced robot-position uncertainties in deburring and a feed-back system working according to the prescribed controlled strategy. Experimental verifications on aluminum work parts have shown satisfactory results. Dornfeld [29] introduced the fundamental principles of using acoustic emission (AE) in chamfering and deburring operations and verified his approach through experimental works on 6061-T6 aluminum alloys.

An overview of a robot arm combined with deburring brush is depicted in Figure 17 [30]. Hirabayashi *et al.* [31] presented deburring robots equipped with force sensors for automatic deburring of elevator guide rails. The more widely used applications employ advanced robots that use five-axis compliant tools, capable to remove most, but not all burrs [3].

Other deburring methods

Wide range of deburring methods which could be used for aluminum works parts were presented in [3]. Amongst, a deburring method for milled surfaces was proposed in [32]. In this work, an inductor producing a co-current magnetic field is adapted to the milling spindle. Ultrasonic deburring of aluminum work parts was reported in [33]. It was found that the distance between the horn and the workpiece and size of abrasive are the governing factors on ultrasonic deburring. A deburring method using enhanced ultrasonic cavitation without abrasives was proposed in [34].

Figure 17. A robot arm combined with deburring brush [30]

Experimental results confirmed that enhanced cavitation bubbles can remove the burrs on aluminum work parts. Micro burrs removal was presented in [35; 36]. The electrochemical deburring (ECD) can be used for deburring conductive metals of any size or shape, including aluminum alloys [3]. This method is ideal when removal of inaccessible burrs in aluminum work parts and generating the surfaces free of scratch are demanded. However the ECD applied to aluminum alloys with high silicon contents generate textured than smooth surface.

According to [3], thermal energy deburring (TEM) is used for deburring of heat sinks made of aluminum alloys. This technique is also used for thick burrs removal of thin components. Other methods such as electro polishing can be only applied for small burrs removal. Polycarbonate shots are mainly used for deburring aluminum machined parts, such as transmission parts, pistons and gears [3].

One of the major reported techniques for burr removal in aluminum machined part is mass finishing. This approach includes vibratory finishing; barrel deburring, roll-flow finishing, centrifugal barrel finishing and centrifugal disc finishing. The overview of advantages and disadvantages of these methods are presented in [3].

4. Conclusion

In this article, an overview of burr formation and deburring processes was presented. The most highly used mechanical deburring processes on aluminum works parts were introduced. Furthermore an insight into application of some other deburring methods on aluminum alloys was presented.

The knowledge of each deburring method and the requirements of the finished products, in addition to burr size are major parameters for correct selection of deburring method. Other important parameters include the versatility, automation, precision cost of method and production volume.

Developing the links between burr sizes and deburring methods would be beneficial for better selection of deburring methods. This sometimes requires combination of several deburring process to gain better results.

An adequate selection of deburring process not only leads to better surface finish, but also reduces the manufacturing cost and increases the production rate.

References:

[1] R.Narayanaswami,D. Dornfeld, Transactions of the North American Manufacturing Research Institute of SME 1994. 22 (1994) 313-322.

[2] L.Gillespie,Manufacturing Engineering(USA) 116 (1996) 69-70.

[3] L. Gillespie, Deburring and edge finishing handbook, Society of Manufacturing Engineers (SME), Dearborn, MI ,USA, 1999.

[4] J.C. Aurich, D. Dornfeld, P.J. Arrazola, V. Franke, L. Leitz, S. Min, CIRP Annals - Manufacturing Technology 58 (2009) 519-542.

[5] S.A. Niknam, V. Songmene, Proceeding of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, In press (2013).

[6] Y. Zedan, V. Songmene, J. Kouam, J. Masounave, International Journal of Machining and Machinability of Materials 13 (2013) 231-252.

[7] F. Schäfer, Entgraten, Krausskopf, 1975.

[8] A. Rangarjan, Optimization of face milling process- Tool path and process planning techniques, Ph.D Thesis, University of California at Brekeley, USA, 2005.

[9] S.A.Niknam,V. Songmene, The International Journal of Advanced Manufacturing Technology 66 (2013) 2029-2039.

[10] L.R.K. Gillespie, Deburring technology for improved manufacturing, Society of Manufacturing Engineers (SME), Dearborn, MI, USA, 1981.

[11] K. Przyklenk, Advances in Non-traditional Machining, ASME, PED 22 (1986) 101-110.

[12] T. Ioi, M. Matsunaga, H. Kobayashi, Paper, MR (1981) 81-389.

[13] A.P.Thilow,Entgrattechnik: ntwicklungsstand und Problemlösungen, expert verlag, 2008.

[14] H. Beier, R. Nothnagel, Development of a high-speed-deburring tool, University of California, Brekley, 2004, 271-279.

[15] M.C. Avila, J. Choi, D.A. Dornfeld, M. Kapgan, R. Kosarchuk, LMA. Annual Reports 2003–2004, UC Berkeley (2004) 10-20.

[16] B. Mchugh, Flexible Finishing with Dry Blast Deburring, Society of Manufacturing Engineers (1988) 1-24.

[17] http://www.weilercorp.com/, Automotive Aluminum Cylinder Heads Deburring, 2013.

[18] D.Dornfeld,Burr formation, Burr Minimization and Deburring seminar: CRIAQ MANU-409C Automated deburring and part finishing Ecole de technologie superieure (ETS), 2009.

[19] C.-H. Cho, K.-H. Kim, Journal of Materials Processing Technology 212 (2012) 1132-1138.

[20] K. Kim, C. Cho, S. Jeon, K. Lee, D. Dornfeld, Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 217 (2003) 1327-1331.

[21] K.U. Lee, S.L. Ko, Journal of Materials Processing Technology 201 (2008) 454-459.

[22] F.J. Xi, L. Liao, R. Mohamed, K. Liu, in, Smart Devices and Machines for Advanced Manufacturing, Springer, 2008, pp. 137-166.

[23] J.F.G. Oliveira, C.M.O. Valente, Monitoring and Control in Abrasive Robotic Deburring Operations, AC (2004) 1-8.

[24] K. Lee, H. Huang, S. Lu Adaptive Hybrid Impedance Force Control of Robotic Deburring Processes (2001) 1-6.

[25] N. Asakawa, K. Toda, Y. Takeuchi, Robotics and Computer-Integrated Manufacturing 18 (2002) 379-385.

[26] R. Bogue, Industrial Robot: An International Journal 36 (2009) 6-12.

[27] H. Zhang, H. Chen, N. Xi, G. Zhang, J. He, On-line path generation for robotic deburring of cast aluminum wheels, IEEE (2006) 2400-2405.

[28] H. Kazerooni, Control Systems Magazine, IEEE 8 (1988) 21-25.

[29] D.Dornfeld,CIRPAnnals-Manufacturing Technology 41 (1992) 93-96.

[30] M. Means, Tooling and Production 51 (1986) 47–51.

[31] H. Hirabayashi, S. Ohwada, I. Yoshida, M. Miki, Force-Control Deburring Robots, Society of Manufacturing Engineers (1987) 1-12.

[32] M. Anzai, H. Otaki, E. Kawashima, T. Nakagawa, Int. J. Jpn. Soc. Precis. Eng.(Japan) 27 (1993) 223-224.

[33] S. Lee, H. Choi, G. Kim, Y. Choi, S.L. Ko, Micro Deburring Technology Using Ultrasonic Vibration with Abrasive (2004) 477-482.

[34] C.Q.Wu,N. Nakagawa, S.F. Zhou, Advanced Materials Research 512 (2012) 1877-1881.

[35] S. Ko, Y.M. Baron, J. Park, Journal of materials processing technology 187 (2007) 19-25.

[36] H. Choi, S. Lee, G. Kim, Y. Choi, S.-L. Ko, Micro Deburring Technology Using Ultrasonic Vibration with Abrasive, Consortium on Deburring and Edge Finishing, UC Berkeley-USA, 2004.