November-December 2019
ISSN: 0193-4120 Page No. 4258 - 4265

A review on Magnetic Abrasive Finishing Process for Finishing a Work piece Surface

Ali Majid Nahi,[1] Ali Hussain Khadum[1]

[1]Mechatronic Engineering department, Al-Khawarizmi College of Engineering,University of Baghdad, Baghdad-Iraq

Article Info
Volume 81
Page Number: 4258 - 4265
Publication Issue:
November-December 2019

Article History

Article Received: *5 March 2019*
Revised: *18 May 2019*
Accepted: *24 September 2019*
Publication: *20 December 2019*

Abstract:
Magnetic abrasive finishing (MAF) process is a process that often occurs at the end of machining operations for the purpose of finishing the surface of the workpiece. MAF process uses the effect of the magnetic field to control the ferromagnetic abrasive powder. The powder usually consists of an iron (ferromagnetic) powder mixed with a high strength non-ferromagnetic powder, like tungsten carbide, and brass alloy. The non-ferromagnetic powder is used to increase the strength of the abrasive powder. In theMagnetic abrasive finishing process, six parameters are used: viscosity, doze (Quantity of the powder), the distance between the pole and the workpiece, pole diameter, pole rotational speed, and current.Each parameter has three levels of variance. In this paper, an attempt has been made to review and compare different methods for finishing the surface of the workpiece.

Keywords: *Magnetic abrasive, finishing, workpiece, ferromagnetic, non-ferromagnetic*

Introduction

The procedure of “Magnetic abrasive finishing (MAF)” comprises of a combination of mechanical as well as an electrical process. It is used to remove metal from a magnetic and non-magnetic workpiece. The diagram in Figure 1 shows the working principle of the process consists of core, coil, pole, powder, and workpiece, that is rotated in the field of current. The coil connected to DC power supply. The gap filled with powder between tool and workpiece. The magnetic abrasive finishing is the process of micro-cutting operation that occurs at the work piece’s surface for the purpose of obtaining a super smooth surface which is smoother than the one obtains as a result of grinding, lapping and honing. This operation is considered as non-traditional machining. The magnetic –abrasive finishing method (MAF) is used for the purpose of cleaning, polishing of different surfaces and Removal of oxide films and layer, there are many applications of (MAF) polishing surfaces to improve surface roughness, conditioning surfaces for welding, conditioning surfaces before painting, coating, deburring and blunting sharp edges [1]. Finishing surfaces to increase the resistance of corrosion, wear and increasing mechanical properties [2].The physical properties are greatly affected by finishing operation.These properties include corrosion, strength, and fatigue[3]. There are many finishing operation some of them are traditional such as grinding, honing [4], and lapping[5].The traditional machining operations should have direct contact between the tool and the workpiece. The other type of machining operation called the non-traditional machining operation, which doesn't have direct contact between the tool and the workpiece. These operations include the ultrasonic machining (USM)[6], magnetic abrasive finishing (MAF)[7], abrasive jet machining (AJM)[8].

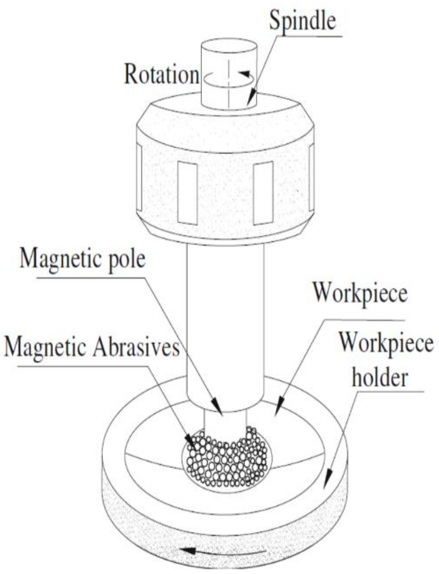

Figure 1. Magnetic abrasive finishing diagram [9]

Harry P. Coats[10] mentioned MAF in 1938 in a registered patent. This method produces a better finishing for the surface. This technique is known to be effective as compared to the traditional techniques for finishing (such as honing, polishing, belt grinding and superfinishing).

The process of Magnetic abrasive finishing

Magnetic abrasive finishing is the operation of removing the material as an effect of a force made by electromagnetic energy [11]. This process is used to minimize the chance of micro-cracks that happens on the work piece'ssurface, which is considered as a defect that may affect the performance of the workpiece [12]. The principle of the MAF method is a ferromagnetic abrasive powder controlled by the electromagnetic field to micro-cut from the surface of the workpiece. The electro-magnetic field is generated by the electricity passing through the wires of the coil, gathered by the core of the coil, passed to the pole that concentrates the magnetic field, which controls the abrasive. A "magnetic abrasive flexible brush (MAFB)" is developed because of the electro-magnetic field on the pole. MAFB works as a multi-point cutting tool. When the pole is rotated the brush moves also causing the removal of the material of workpiece.

Types of magnetic abrasive finishing

There are many shapes can be machined using MAF, these shapes are flat-surfaced, bolt, thread surface, thin plates, external and internal cylindrical surfaces, and internal finishing of hollow surfaces. Figure 2 to Figure 6show the types of MAF processes.

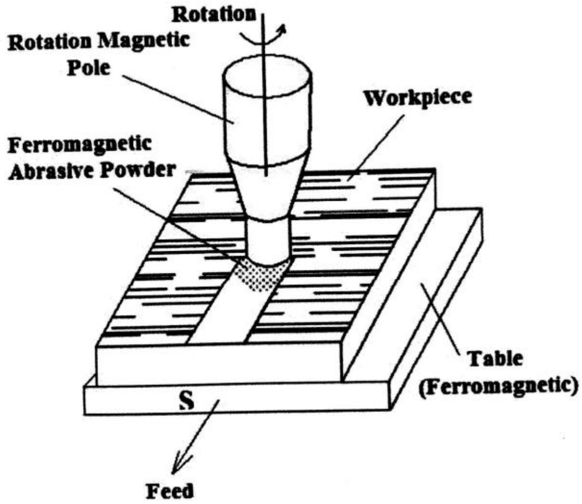

Figure 2. MAF process for flat surface[13]

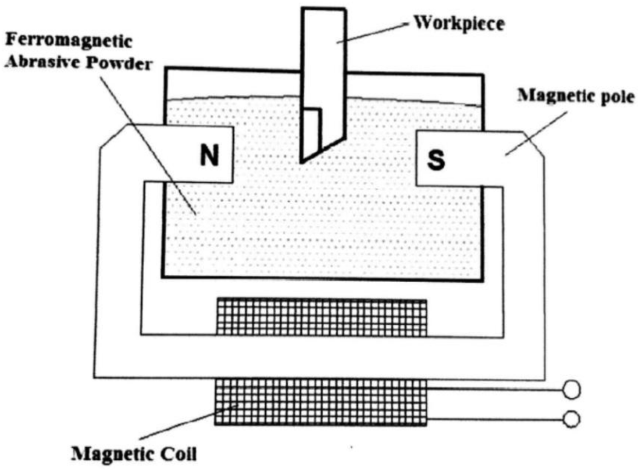

Figure 3. MAF process for flat surface[13]

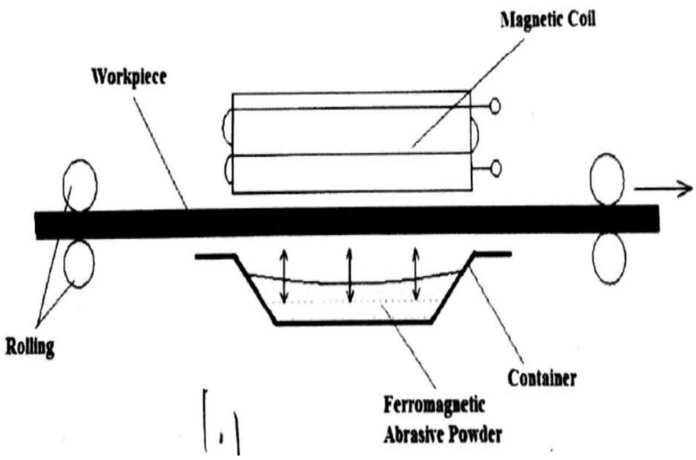

Figure 4. MAF process for thin plates[13]

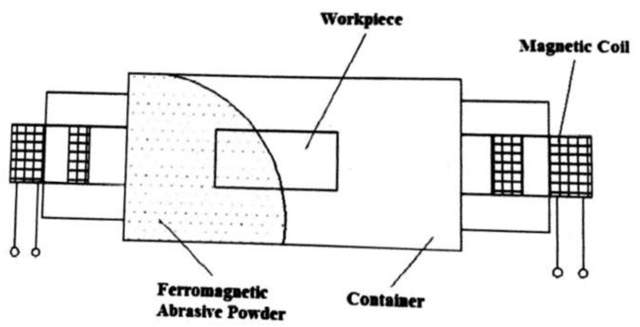

Figure 5. MAF process for hollow surface[13]

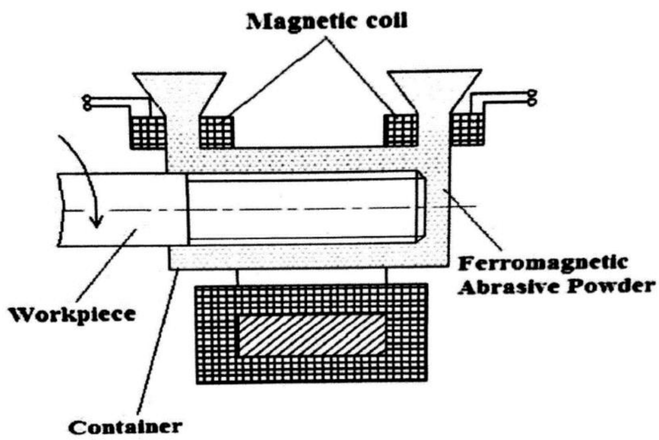

Figure 6. MAF process forbolts and threads[13]

Advantages of MAF Process

Magnetic abrasive finishing has many advantages which include

a) Many shapes can be finished such as external and internal surfaces, flat surfaces, thin plates, etc.
b) It is used for both ferromagnetic and non-magnetic motels
c) MAF gives a good surface finish (R_a = 0.003µm)
d) Temperature doesn't exceed 473 k°.
e) There is no direct contact between the tool and workpiece, so the tool doesn't wear.
f) The powder has no bond and the elasticity of the powder can be controlled by the electromagnetic field.[14]-[15]

Disadvantages of MAF Process

MAF hasa little disadvantage that includes

a) Low productivity
b) A small amount of the material is removed
c) Forming a curvature surfaces[16]

Application of MAF Process

The MAF applications are

a) Superfinishing of different shapes like thread, gear, and flat surfaces
b) It treats the defects on the surface
c) Increase the wear and corrosion resistance of the workpiece.
d) Oxide layer removal
e) Removing Burs that occur because of drilling
f) Surface conditioning for welding.[17]

The literature on Process Plane MAF for Different Types of Surfaces

Nazar M.naif (2012) [18] machined the brass plate surface by using MAF. The brass surface is known to be difficult to machine using traditional machining operations. He used the Taguchi method to evaluate surface roughness and the consequent effects from different parameters. The parameters include current, gap and rotational speed of pole. He concluded that the most significant parameter on the roughness was the rotational speed of the pole.

An-yuan Jiou (2015) [19] applied axial pressure on the surface with MAF by using a plate to determine the quality of the surface. The parameter studies were distance or gap and pressure applied. These initial parameters are used to draw comparisons between the material that is removed from the surface and test it under various conditions. The final results can be used to determine the surface roughness to improve the efficiency of the material being removed and the final cross-sectional form when using low pressures. When it was compared with higher traditional methods of applying higher axial pressure, it can be found that the efficiency decreases, and the surface roughness increases. It was also found that using a lower axial pressure improved the final cross-sectional form.

Baljinder Singh and Charanjit Singh (2015) [20] also produced composite aluminum oxide (Al_2O_3) that is magnetically sintered with 20% in abrasives and 80% in iron with both having a mesh size of 300. Brass tubes were experimented upon and the different abrasion levels (5gm, 10gm, and 15 gm), abrasion mesh sizes (120, 180 and 220) were used to determine

November-December 2019
ISSN: 0193-4120 Page No. 4258 - 4265

the effectiveness. The workpiece rotation speed was also adjusted (200 rpm, 400 rpm, and 600 rpm), along with the machine use time (20 mins, 50 mins, and 80 mins) and consequently, the workpiece gap (2mm, 4mm, and 6mm) was also adjusted. The optimal conditions were found as 15gm of magnetic abrasive, a mesh size of 220 of abrasive particles, a 4mm workpiece gap and a workpiece rotation speed of 600rpm and a total machine process time of 80 mins.

M.G.Patil et al. (2012) [17] conducted a study on Stainless Steel 304 tubes by performing MAF to study the various external factors such as the abrasion, machine process time, the speed of workpiece rotational speed, the magnetic flux, and density and lubricant. The analysis was done on the surface roughness percentage to improve the finish and also to determine the effectiveness of the abrasion using the iron powder and silica combination.

Wei-Liang Ku and Han-Ming Chow [21] have studied MAF using a magnetically sintered abrasive which has a combination of Al_2O_3 and Fe on a cylindrical steel tube. ANOVA is conducted after performing statistical to predict the surface finish using the constructed parameters. A system prediction accuracy of 97% was found. They used four parameters to study MAF which was the rotational speed, current, vibration frequency, abrasive and concluded that all the four parameters were significant after making 81 experiments. Finally, they reach the optimum mirror surface of the tube and made an analytic model by using ANOVA to predict the results.

M. Vahdati and S. A. Rasouli (2017)[22] used a combination of the MAF process and the computer numerical control to perform the operation of machining a free form surface. Certain parameters were monitored closely such as the workpiece gap, rotational speed of the machining head, amount of abrasive powder and the feed rate to determine the surface roughness. The conclusion drawn was to find that the optimum conditions for the experiment are a feed rate of 100mm/min, gap size of 0.5 mm and rotational speed of 2100 rev/min and powder amount of 1.75 g. To help understand the effectiveness of the MAF, two types of microscopy are carried out, electron and atomic force microscopy.

Ching-Tien Lin et al. (2007) [23] machined a free form stainless steel SUS surface. Taguchi orthogonal array was used and the parameters that were taken are (working gap, feed rate, a mass of the abrasive). The finishing process included two steps, the first step included a rough finishing which provides R_a=2.670 µm, second step includes the use of MAF process that gives R_a=0.158 µm. This case resulted in ideal conditions using a 2 g of abrasive powder, a workpiece gap of 2.5 mm and a 10 mm/min feed rate. It was found that the rotational speed of the spindle did not impact the surface roughness significantly.

Amorim H. J. et 2007 [24] evaluated the MAF process and its dependency on the input working parameters. A cylindrical ABNT 1045 steel workpiece is machined down by using a magnetic brush, with Fe and Al_2O_3 composite mixture. This was acted upon by the magnetic field and as before, the parameters monitored were the rotation speed of the workpiece, the processing time, the grain size of the abrasive and the magnetic powder. The limiting factor here was found out to be the machine process time and has the greatest impact followed by the abrasive grain size and the workpiece rotation speed. The surface roughness $R_a$was reduced to $0.7\mu m$ from $2.5\mu m$. This was allowed due to the higher rotation speed combined with the smaller abrasive grain size.

F. Djavanroodi 2013 [25] identified that intensity of the magnetic field, the workpiece rotational velocity and the processing time impacting the surface roughness using MAF in a brass shaft (Cu_3Zn_7). It was concluded that the magnetic field had the greatest impact on the finishing process. A higher magnetic field density causes a greater change in the obtained surface roughness and longer process time improves the surface smoothness and the consequences, a lower workpiece velocity also reduces surface roughness.

The literature onParameters that affect MAF Process

Dhirendra K. Singh et al.(2004) [26] quantified the quality of finish on the surface using a series of Taguchi design experiments to monitor closely the DC voltage applied, the workpiece gap and its rotational speed and the mesh size of the abrasive. The voltage was found to be the most critical parameter with an ideal value of 11.5 V followed by the workpiece gap of

1.25 mm, a rotational speed of 180 rev/min and a high mesh number to improve R_a. By obtaining linear regression models, it was found that R_a increased with the voltages increase and higher working gaps.

Amit M. Wani et al. 2007 [27] used a finite element model of the flow finishing MAFF using the magnetic abrasive to compare between the theoretical and experimental work. It has been concluded that the surface roughness and material removed increases with a higher abrasive density, grit size and a stronger magnetic field. The pressure also increases between the abrasive and the workpiece.

P.I. Yascheritsin et al 1997[28] studied the MAF of internal round surfaces. It is stated that it is allowable to improve the surface quality through the machining process under the MAM method. The increasein the residual compression stresses also causedthe hardening of the surface layer. After MAM using the roughness was reduced, surface profile possesses the form, which increases contact hardness.

T. Furuyaa, Y. et al.[29] proposed a new surface finishing using a micro-3D structure on the metal surface which utilized a polishing fluid known as magnetic compound fluid (MCF). This method is also a contact-free method. The polishing liquid is a combination of magnetic particles which are Nano-sized and iron particles on the micro-sized level. Itis alsoconsisting of $10\mu m$ cellulose fiber along with micro-sized particles which are influenced by the magnetic field. From the results, it has been concluded that:

- The amount of material removed is reduced when only the upper magnet is installed to apply the magnetic field versus a magnetic on the top and bottom.
- Using larger abrasive particles leads to a smoother surface and more material removed when used for polishing.
- The optimal conditions require an abrasive concentration of 20w.t.% and 20-40w.t.% for Fe. These optimal concentrations are respective of the polishing characteristics in the MCF polishing liquid.

Yan Wang et al.[30] observed the quality of the inner surface finish that was obtained using a magnetic abrasive. It has been concluded that the polishing speed, the material used for the abrasive and the magnetic particles and their grain size along with the supply of the magnetic abrasive supply have a major impact on the quality of the inner finish and the MRR. It has also been demonstrated how the microstructure of the inner region changes during the finishing process.

Shaohui Yin et al.[31]stated the objectives of the project to an autonomous or relatively simple finishing process that can allow both unskilled and skilled workers to operate on the complicated microstructure surfaces and edges of the magnesium allow. The first phase of the study brought into focus the deburring of the alloy on the characteristics of the plane and the edges of the allow using a vertical vibration-assisted magnetic finish method.

Hence, the process seems to be able to demonstrate an efficient finishing of magnesium allow. Also, the magnesium alloy's removal volume per unit time was greater as compared to any other materials, for instance, stainless or brass. Thus, with magnesium alloys, increased efficiency finishing has been achievable. Using the MAF process allows for easy removal in a short time of the micro-burr of magnesium alloy. Moreover, along with vertical vibration assistance, the deburring efficiency considerably increases.

V.K. Jain et al. (2001) [32] studied a workpiece and the gap effect on it. Magnetic Abrasive Finishing (MAF) was used in their research. This procedure involves placing the workpiece amid two magnets. The researchers utilized the MAF method for processing workpieces of cylindrical shape. The lubricant used was servospin-12 oil in addition to an abrasive powder ($Al2O3$ of 600 mesh size (25.7μm)) along with a 300-mesh size (51.4μm) In terms of the material removal, the circumferential speed, as well as the effects of the working gap, were investigated. It was then found that with an increase in the working gap or decrease in the circumferential speed of the workpiece, the material removal decreases. In addition, increasing circumferential speed of the workpiece results in an increase in the change in surface finish.

Yahya M. Hamad 2010 [33] also made use of the MAF procedure for improving as well as finishing the

November-December 2019
ISSN: 0193-4120 Page No. 4258 - 4265

quality of a "ferromagnetic stainless steel 420 plate". In their study, it was revealed that a change in the operational variables (such as table stroke, feed rate, coil current as well as working gap) can have an influence on the overall workpiece's surface quality. Furthermore, the working gap was the most significant parameter, after which followed the supplied current. Feed rate, as well as the working stroke, were revealed to have a minor influence on the change in the roughness of the workpiece.

Saheb.M.Hameed 2018 [34] studied MAF process on ferromagnetic (workpiece) stainless steel 420 plate by using Taguchi method to prepare an important four parameters which are dose (volume of powder, finishing time, feed rate and current (DC) Using response surface methodology (RSM) to find their influence on the surface roughness and concluded that feed rate and finishing time are found to be the most significant parameters followed by dose(volume of powder) and then the current.

PALWINDER SINGH et al. 2011 [35] studied the effect of the MAF process on the inner surfaces. They studied the effect of rotational speed (rpm), magnetic flux density, grit size and quantity of abrasives and concluded that percent improvement in surface finish was significantly affected by magnetic flux density, quantity of abrasives, interactions between rotational speed of workpiece & magnetic flux density, rotational speed & grit size, rotational speed & quantity of abrasives, magnetic flux density & grit size, magnetic flux density & quantity of abrasives.

Lieh-Dai Yang et al. 2009 [36] used oil and water as a cooling liquid The operations were performed using Taguchi experimental design, the parameters they studied were a magnetic field, pole rotational speed, feed rate, working gap, abrasive, and lubrication. The optimal parameter conditions were obtained after experimental data analysis, the quality surface roughness (R max = 0.1 mm) which is a mirror surface was obtained after confirmatory tests. The optimal parameter conditions for material removal weight were also obtained in MAF. The significant parameters were surface roughness, working gap, feed rate, and abrasive. Also, there were three different magnetic poles such as a solid cylindrical pole, a hollow cylindrical pole, and a hollow cylindrical pole with grooves design. The results showed that the hollow cylindrical with grooves can generate better surface roughness in MAF.

Sehijpal Singh and R.Grill 2015 [37] compared the results obtained by the MAF process with the results obtained by buffing.They used three parameters to study the surface roughness. The parameters were current, machining time and the rotational speed. They concluded that magnetic abrasive finishing (MAF) process gives a better result than the buffing process.

Conclusions

It is noted from all the studiedresearches that the effect of the parameters (Gap, Speed, Current, of pole and doze of powder) on the Ra and Hv and the effect of the tank. All the parameters above have a significant influence on the MAF process. In this study, all four parameters were studied besides the viscosity of the oil and the diameter of the magnetic pole.

Most of the researchers used this method without an environment in a normal condition. Only a few of them used liquids as a cooling liquid.None of them has used the oil as an environment of MAF. Since MAF is based on the principle of friction, and oil is well known as a factor that is used to minimize friction.

References

[1] T. W. Kim and J. S. Kwak, "A study on deburring of magnesium alloy plate by magnetic abrasive polishing," Int. J. Precis. Eng. Manuf., vol. 11, no. 2, pp. 189–194, 2010.

[2] G. W. Chang, B. H. Yan, and R. T. Hsu, "Study on cylindrical magnetic abrasive finishing using unbonded magnetic abrasives," Int. J. Mach. Tools Manuf., vol. 42, no. 5, pp. 575–583, 2002.

[3] P. Jayakumar, "Magnetic-abrasive machining," Met. Finish., vol. 99, no. 4, p. 98, 2001.

[4] S. Abrate and D. A. Walton, "Machining of composite materials. Part I: Traditional methods," Compos. Manuf., vol. 3, no. 2, pp. 75–83, 1992.

[5] B. H. Yan, H. J. Tzeng, F. Yuan Huang, Y. C. Lin, and H. M. Chow, "Finishing effects of spiral polishing method on micro lapping surface," Int. J. Mach. Tools Manuf., vol. 47, no. 6, pp. 920–926, 2007.

[6] R. V. Rao, P. J. Pawar, and J. P. Davim, "Parameter optimization of ultrasonic machining process using nontraditional optimization algorithms," Mater.

Manuf. Process., vol. 25, no. 10, pp. 1120–1130, 2010.

[7] I. T. Im, S. D. Mun, and S. M. Oh, “Micro machining of an STS 304 bar by magnetic abrasive finishing,” J. Mech. Sci. Technol., vol. 23, no. 7, pp. 1982–1988, 2009.

[8] N. D. Chakladar and S. Chakraborty, “A combined TOPSIS-AHP-method-based approach for non-traditional machining processes selection,” Proc. Inst. Mech. Eng. Part B J. Eng. Manuf., vol. 222, no. 12, pp. 1613–1623, 2008.

[9] M. Vahdati and A. Shokuhfar, “A trend toward abrasiwe nano finishing of plane surfaces with magnetic field energy,” Materwiss. Werksttech., vol. 39, no. 2, pp. 167–170, 2008.

[10] L. Singh, S. S. Khangura, and P. S. Mishra, “Performance of abrasives used in magnetically assisted finishing: A state of the art review,” Int. J. Abras. Technol., vol. 3, no. 3, pp. 215–227, 2010.

[11] T. Mori, K. Hirota, and Y. Kawashima, “Clarification of magnetic abrasive finishing mechanism,” J. Mater. Process. Technol., vol. 143–144, no. 1, pp. 682–686, 2003.

[12] J. Guo, “Investigation on Surface Integrity of Rapidly Solidified Aluminum RSA 905 by Magnetic Field-Assisted Finishing.”

[13] Y. M. Baron, “magnetic abrasive and magnetic finishing of products and cutting tools,” leningrad, pp. 138–139, 1986.

[14] R. S. Mulik and P. M. Pandey, “Magnetic abrasive finishing of hardened AISI 52100 steel,” Int. J. Adv. Manuf. Technol., vol. 55, no. 5–8, pp. 501–515, 2011.

[15] N. T. Nguyen, T. N. Tran, S. H. Yin, M. Q. Chau, and D. H. Le, “Multi-objective optimization of improved magnetic abrasive finishing of multi-curved surfaces made of SUS202 material,” Int. J. Adv. Manuf. Technol., vol. 88, no. 1–4, pp. 381–391, 2017.

[16] F. F. Mustafa, “The Influence of the Magnetic Abrasive Finishing Cylindrical Surfaces Cylindrical Surfaces on the Surface Roughness and MRR,” vol. 11, no. June 2015, pp. 1–10, 2016.

[17] M. G. Patil, K. Chandra, and P. S. Misra, “Study of Mechanically Alloyed Magnetic Abrasives in Magnetic Abrasive Finishing,” Int. J. Sci. Eng. Res., vol. 3, no. 10, pp. 1–5, 2012.

[18] M. Nazar, “Study on the Parameter Optimization Inmagnetic Abrasive Polishing Forbrass Cuzn33Plate Using Taguchi Method,” Iraqi J. Mech. Mater. Eng., vol. 12, no. 3, pp. 596–615, 2012.

[19] A. Y. Jiao, H. J. Quan, Z. Z. Li, and Y. H. Zou, “The study of plane magnetic abrasive finishing based on axial pressure,” Int. J. Mach. Mach. Mater., vol. 17, no. 5, pp. 418–433, 2015.

[20] B. Singh and C. S. Kalra, “Optimization of Magnetic Abrasive Finishing Parameters during finishing,” pp. 1810–1817, 2015.

[21] C. L. Hung, W. L. Ku, and L. D. Yang, “Prediction system of magnetic abrasive finishing (MAF) on the internal surface of a cylindrical tube,” Mater. Manuf. Process., vol. 25, no. 12, pp. 1404–1412, 2010.

[22] M. Vahdati, S. A. Rasouli, M. Vahdati, and S. A. Rasouli, “The International Journal of Surface Engineering and Coatings Study of magnetic abrasive finishing on freeform surface Study of magnetic abrasive fi nishing on freeform surface,” vol. 2967, no. February, 2017.

[23] O. L. A. Cle, “Study of magnetic abrasive finishing in free-form surface operations using the Taguchi method,” pp. 122–130, 2007.

[24] Amorim, H. J., Gomes, M. S., Lorini, and F. J., “parametric evaluation of cylindrical magnetic abrasive finishing process,” J. Mater. Process. Technol., pp. 5–9, 2007.

[25] F. Djavanroodi, “Artificial neural network modeling of surface roughness in magnetic abrasive finishing process,” Res. J. Appl. Sci. Eng. Technol., vol. 6, no. 11, pp. 1976–1983, 2013.

[26] D. K. Singh, V. K. Jain, and V. Raghuram, “Parametric study of magnetic abrasive finishing process,” Journal of Materials Processing Technology, vol. 149, no. 1–3. pp. 22–29, 2004.

[27] A. M. Wani, V. Yadava, and A. Khatri, “Simulation for the prediction of surface roughness in magnetic abrasive flow finishing (MAFF),” Journal of Materials Processing Technology, vol. 190, no. 1–3. pp. 282–290, 2007.

[28] P. I. Yascheritsin, L. E. Sergeev, and M. I. Sidorenko, “Comparative appraisal of quality characteristics of holes after different finishing methods,” Adv. Perform. Mater., vol. 4, no. 3, pp. 337–347, 1997.

[29] T. Furuya, Y. Wu, M. Nomura, K. Shimada, and K. Yamamoto, “Fundamental performance of magnetic compound fluid polishing liquid in contact-free polishing of metal surface,” J. Mater. Process. Technol., vol. 201, no. 1–3, pp. 536–541, 2008.

[30] Y. Wang and D. Hu, “Study on the inner surface finishing of tubing by magnetic abrasive finishing,” Int. J. Mach. Tools Manuf., vol. 45, no. 1, pp. 43–49, 2005.

[31] S. Yin and T. Shinmura, “Vertical vibration-assisted magnetic abrasive finishing and deburring for magnesium alloy,” Int. J. Mach. Tools Manuf., vol. 44, no. 12–13, pp. 1297–1303, 2004.

[32] V. K. Jain, P. Kumar, P. K. Behera, and S. C. Jayswal, "Effect of working gap and circumferential speed on the performance of magnetic abrasive finishing process," vol. 250, pp. 384–390, 2001.

[33] Y. M. Hamad, "Improvement of Surface Roughness Quality for Stainless Steel 420 Plate Using Magnetic Abrasive Finishing Method," vol. 6, no. 4, pp. 10–20, 2010.

[34] S. M. Hameed, "The Effect of Operating Parameters of MAF Process on the Surface Roughness for Ferromagnetic Materials," no. 4, pp. 64–73, 2018.

[35] P. Singh, "Internal Finishing of Cylindrical Pipes Using Sintered Magnetic Abrasives," Int. J. Eng. Sci. Technol., vol. 3, no. 7, pp. 5747–5753, 2011.

[36] L. D. Yang, C. T. Lin, and H. M. Chow, "Optimization in MAF operations using Taguchi parameter design for AISI304 stainless steel," Int. J. Adv. Manuf. Technol., vol. 42, no. 5–6, pp. 595–605, 2009.

[37] H. Yamaguchi, J. Kang, and F. Hashimoto, "Metastable austenitic stainless steel tool for magnetic abrasive finishing," CIRP Ann. - Manuf. Technol., vol. 60, no. 1, pp. 339–342, 2011.

[38] C. Vidal and V. Infante, "Optimization of FS welding parameters for improving mechanical behavior of AA2024-T351 joints based on taguchi method," J. Mater. Eng. Perform., vol. 22, no. 8, pp. 2261–2270, 2013.

[39] E. B. Dean, "Taguchi Approach to Design Optimization for Quality and Cost: An Overview," pp. 1–10, 1991.

[40] V. Jigar Talati, Hexagon Design Centre, "Surface Roughness – Significance and symbol interpretation in drawing," Br. J. Psychiatry, vol. 112, no. 483, pp. 211–212, 1966.

[41] MAF Machine Manual

[42] W. D. Callister and J. Wiley, Materials Science. .

[43] S. D. Mun, "Micro machining of high-hardness materials using magnetic abrasive grains," Int. J. Precis. Eng. Manuf., vol. 11, no. 5, pp. 763–770, 2010.

[44] Erik Oberg, Franklin D. Jones,Holbrook L. Harton and Henry H. Ryffel " machinary handbook" 24th edition

[45] Ranjit K. Roy, a primer on the Taguchi method, 1st edition (new york nosteand 1990).