Application of Polishing AISI 316L Stainless Steel Ball Bearing with A Magnetic Abrasive Finishing Process: A Review

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Abstract

Advanced machining process has been demonstrated to be suitable in engineering process technology for surface finishing with material removal process or with the traditional finishing processes: a fundamental, unrestrained and a high demand in labor phase during the production. Magnetic abrasive finishing, one of them assisted by polishing and a nonconventional process capable for a precision finishing with machining forces controlled by a magnetic field and it is not applicable for some complex process where conventional finishing technique can be simply applied. This paper review the practical technique to polishing an AISI 316L ST Ball bearing with the magnetic abrasive finishing process for finishing the external sphere surface design. The different input parameter of the process is reviewed such as electromagnetic speed, current and the direct voltage induced, magnetic flux density, the quantity of abrasive particles size, working environment, and workpieces materials. The process input validates the performance of material removal rate and surface roughness of the finishing process of the stainless steel ball bearing.

Keywords: *abrasive, polishing, stainless steel, surface finish, roughness, ball bearing*

Abstrak

Advanced machining process telah terbukti dalam teknologi proses rekayasa untuk *surface finishing* dan proses material *removal*, atau dengan proses *traditional finishing: fase fundamental, unrestrained,* dan permintaan tinggi dalam fase tenaga kerja selama produksi. *Finishing abrasif magnetik,* pada *polishing* dalam proses *non-konvensional* mampu menyelesaikan dengan presisi dengan proses pemesinan yang dikontrol oleh medan magnet dan itu tidak berlaku untuk beberapa proses kompleks di mana teknik penyelesaian konvensional dapat dengan mudah diterapkan. Makalah ini mengulas teknik praktis untuk memoles bantalan *AISI 316L ST Ball* dengan proses *finishing abrasif magnetik* untuk menyelesaikan desain permukaan bola eksternal. Parameter input yang berbeda dari proses ditinjau seperti kecepatan elektromagnetik, arus dan tegangan langsung yang diinduksi, kepadatan *fluks magnetik,* jumlah ukuran partikel *abrasif,* lingkungan kerja, dan bahan benda kerja. Input yang terjadi untuk proses *finishing* bantalan bola *stainless steel* dapat memvalidasi kinerja laju material *removal rate* dan *surface roughness.*

Kata kunci: *abrasive, polishing, stainless steel, surface finish, roughness, ball bearing*

1. Introduction

Over the past period, the machining process has been performed in different ways depending on multifunctional materials properties and the attractiveness to its applications function in material's device including ball bearings, actuators, bearings, magneto-electronics, spin-electronics and others [1-2]. Meanwhile, these multifunctional materials can be manufactured by the aid of Nano-particulate powders, thin films, laminated and bulk ceramics shape, steel bars, etc. [1]. The different machining process is required to get the specified material upon on these multifunction. So far, the magnetic abrasive finishing (MAF) assisted-polishing has been introduced as non-conventional machining process from the traditional polishing with an abrasive sandpaper material. This process has been inserted to signify the quality of good surface finish for machined material and to further optimize the operation. In addition, the nonconventional machining was being needed such as MAF and magnetic abrasive machining (MAM) for the better ability of surface finish performance [3] and both operation of surface finishing and deburring are simultaneously performed by the aid of the forces presented during the magnetic field applied in the finishing zone [4].

The surface finish of stainless steel ball require internal and external MAF process such as lapping, buffing, honing and burnishing classified in three classes: MAF with a permanent magnet, MAF with direct current and MAF with alternative current resulting for finishing the internal and external surfaces design of any other multifunctional material. The process of AISI 316 ST ball bearing use an ultra-high-speed magnetic abrasive machining (UHSMAM) to facilitate and prepare the surface finish of stainless steel bars while standby to a specimen to be machined at micro-dimension in material removal [5].

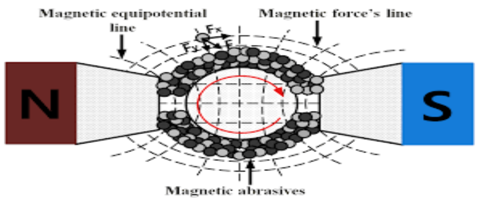


Figure 1. Schematic of the external cylindrical surface of the ball bearing by MAF (6)

MAF is also defined as the process in which mixture of non-ferromagnetic abrasive and the ferromagnetic iron particle is taken and magnetically energized using a magnetic field, see Fig.1 and the specimen is kept between the two Poles North and the South Pole of a magnet filled with magnetic abrasive particle. The magnetic abrasive particles join each other along lines of magnetic force and form a flexible magnetic abrasive brush and it behaves as the multipoint cutting tool for the finishing operation [7] (Patel and Dr. K M, 2014)

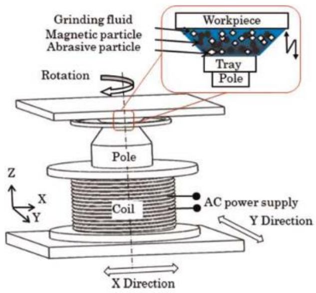


Figure 2. MAF installation,[7]

2. The magnetic abrasive surface finishing machining process

Magnetic abrasive finishing was initiated in the United States, US in the 1930s where its first patent produced in 1940s with a remarkable growth era in the USSR and in Bulgaria, Germany and Poland while the US in 1960s continues the practical usage. In the 1980s the Japanese started to conduct the research with various applications till in the 1990s, where MAF appeared with multifunctional practical in the US as a machining process [9, 4]. The growth of practical usage of materials manufacturing by MAF process such the semiconductor, aerospace materials, and medical devices from optics industries have caused the continued development of enhanced methods for attaining a high form of surface finish accuracy and surface integrity [4].

The MAF also require the non-conventional composite materials widely used in its processes as the specimen such as stainless steels, titanium alloys, tungsten, and other various composites. MAF machining is presented as the simplified process for the composite materials which are difficult-to-cut with the special characteristics such as hardness, high heat and wear resistance, high strength and high chemical composite materials. However these materials have a poor machining accuracy and machinability [10], but its applications in harsh operational conditions and/or in the fields of semiconductors upon its properties, biotechnology operations, medical components operations, and aeronautical/aerospace devices; attract the manufacturers and researchers to continue the research to enhance the process.

In addition to surface finishing of AISI 316L ST ball bearing with MAF, there are other state process applications in many fields, as it has also described by Khayry (2000), Umehara et al. (1997), and Hitomi and Shinmura (1995). According to Hassan Abdel; such applications as a) Polishing of fine components (circuit boards) b) Electroplating by applying a protective coatings to the surface of the layer of a specimen and remove the oxide layers c) Chamfering and deburring of gears and cams, d) Automatic polishing of complicated shapes, e) Polishing of flat surfaces; present the closer similarities with MAF process and it has been developed for a wide variety of applications including the fluid systems, optics, dies and molds, electronic components, microelectromechanical systems, and mechanical components (9). The MAF process provides an advantage of a) Smooth surface finish with high material removal rate MRR, b) Minimizes the micro-cracks and surface damage of work piece, c) Able to produce surface roughness of nanometer range with hardly any surface defects and d) The flexible magnetic abrasive brush requires neither compensation nor dressing,[8].

The various conducted research experiment, see Table 1, shows the effect of input parameters on surface finishing during MAF process where Khairy presented in 2001, the disadvantage effect of rigid shaped and grinding wheels on the magneto abrasive finishing process and this gave an enthusiasm to the research to study the main features of the MAF machining upon the kinematic process present during machining and the outcome investigation on electromagnetic rotational speed, abrasive particles, size dimensions and current intensity in the output parameters called edge and surface finishing with conventional grinding and super finishing method to explain the capabilities of polishing process [11, 3].

Table 1. Input and output parameter for the previous studies with MAF machining process

Authors	*Title*	*Specimen*	*Input parameters*	*Output parameters*	*Conclusion*
(12)	*A Steel Ball Surface Quality Inspection Method Based on a Circumferential Eddy Current Array Sensor*	steel ball bearings	inspect surface defects, coil quality factor, magnetic field intensity, induced eddy current density	number of probe coils, the frequency of excitation current suitable for steel ball, surface defects	CECA sensor may be an option for the effective inspection base on the capability to completely inspect and detect steel ball surface defects as small as 0.05 mm in width and 0.1 mm in depth.
(13)	*Effect of the working gap and circumferential speed on the performance of magnetic abrasive finishing process*	cylindrical workpieces and an abrasive bounded powder ((Fe powder of 300 mesh size (51.4μm)), abrasive powder (Al2O3 of 600 mesh size (25.7μm), and lubricant called servospin-12 oil)	two magnets, cutting force, lathe machine, working gap and magnetic field, circumferential speed,,	material removal, Surface finish,	1. The resulting of the research proved that the material removal decreases by increasing the working gap or decreasing the circumferential speed of the workpiece may cause the change the finish off of the surface roughness. 2. Change in surface finish increases by increasing the circumferential speed of the workpiece.
(4)	*Superfinishing of Alloy Steels Using Magnetic Abrasive*	alloy steels	normal magnetic force, tangential cutting force	working gap values, the magnitude of the force (magnetic force), surface roughness, MRR	The interrelation of magnetic force and tangential cutting force cause the change in Ra which is comparatively weak and give a further study.
(14)	*Clarification of magnetic abrasive finishing mechanism*	planar type process for a non-magnetic material (stainless steel)	magnetic abrasive brush, repulsion between bundles (Faraday effect), line tension, magnetic field force	tangential force, soft surface finish	1. There is brush forming energy involved in the formation of magnetic abrasive brush in the MAF process. 2. Most of the normal force applied within the area of the 1mm radius and the degree Concentration is larger than that of magnetic flux density distribution. 2. The recommendation has been given for the process such as a high voltage level, low MAF working gap, the increase and variable of rotational speed, and large mesh number for improving the surface quality
(15)	*A novel magnetically driven polishing technique for internal surface finishing*	spherical bar magnet	magnetic abrasive particles, abrasive size	surface roughness and material removal	1. The 98% improvement in surface roughness has been obtained for ring polishing exerted on the spherical bar magnet and with 86% for the section polishing improvement. 2. A new proposed method of material removal mechanism for the proposed internal polishing technique based on the experimental results. 3. The researchers may focus on the effect of rotating speed, the gap between external magnet and workpiece, and also abrasive slurry conglomerate to optimize the process.

3. Mechanism of Magnetic abrasive finishing polishing

A Specimen of AISI 316L ST present chemical composition of Carbone (C), Chrome (Cr), Nickel (Ni), Manganese (Mn), Silicon (Si) and Phosphor (P), see Table.1 [16]; these properties enable mechanical properties in the specimen such as heat treatment, welding, machining, hot and cold working. Abdel Hassan presented the rotating motion of spherical magnetic stainless steel ball bearing clamped into the rotating chuck and magnetic field lines inter in contact with the specimen by means of vibratory motion caused by the oscillation motion of two magnetic poles, north and south; relative to the specimen [9]. A mixture of fine magnetic abrasive of 50 to 100 microns conglomerate enter in the contact of the specimen and the magnetic heads pole where resulting in the external spherical surface finishing process by a continuing contact of magnetic fields and the abrasives of 1 to 10 micron of dimension accuracy. The material removal is enabled by the adaptive magnetic abrasive brush which presents the arbitrary bleeding edges and acts as a multi-point cutting device [8].

Table 2. Chemical composition of AISI 304, AISI 316L and AISI 420 stainless steels,[17-18]

AISI	304	316L	420
%C	0.0667	0.0180	1.3450
%Cr	18.1200	16.9280	13.1000
%Ni	9.5800	9.5800	5.300
%Mn	0.6020	0.6020	0.7860
%Si	0.3644	0.3644	0.4049
%Mn	0.2898	0.2898	0.1338
%P	0.0015	0.0015	0.0014

3.1. Different machining operation with the Magnetic Abrasive Finishing process

The geometrical shape of ball bearing characterize with the hardened steel balls and geometrically contact incorporates at a point with an inner and outer race to create high stress dispersed locally along at each contact point. The high speed ball heading machine cut the stainless steel 314L wire rod and compress into the die to form a spherical shape ball with 10 ton withstanding forces and 1000 raw ball/min of production rate. The compressed balls are flashed to remove any uneven surfaces with the help of two cast metal sheets with grooves. After this process the balls which still has the characteristics of uneven surfaces, it is now hardened by a heating process in a furnace to increase its hardness and strength properties. Through the heat treatment and quenching; the ball is heated at 810ºC then quenched at 60ºC; to avoid the breaking; the oil may be used, [4,19].

After the quenching, the ball may be heated again at 170ºC before the polishing process with a precision MAF required to make the smooth spherical shape and provide the specified size dimensions. Furthermore, the MAF process may be needed to smooth the surface and precise the previous grinding process. The process removes any fine unevenness, making the surface sparkling and the ball closer to the spherical shape. The size of the balls by considering the average size margin error must be less than 0.1 micrometers with 16mm diameter and a withstand the weight of 35tons. [10], [19].

Figure 3. A raw ball with an uneven surface [19]

3.1.1. Cold Heading

The process which performed at room temperature, very high speeds of one large ball per second while a small ball is at two to four balls per second. The control process ensures that the die cavity is completely filled and the heading machine cuts off a specified length of the wire material into a cylindrical slug. Two hemispherical halves of the heading die then form the slug into a roughly spherical shape.

3.1.2. Flashing

The simplest unit operations where an excess of materials at the external surface finished of the steel balls are slightly removed by a continuous pass of the ball between two open grooved cast iron plates.

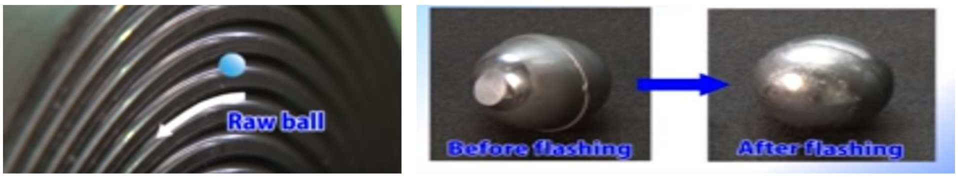


Figure 4. Schematic of raw ball motion during flashing [19]

3.1.3. Heat Treatment

This process combines two others process quenching and tempering process; a furnace in rotation motion ensure the condition of the balls upon its disposition and affect the external surface of the balls. The balls submerged in an oil reservoir gain the high hardness and wear resistance properties from the rapid cooling (oil quenching) which produces martensite. The tempering operation further decreases internal stresses until the final specified hardness range of the bearing is reached. The minimum hardness reached of 30 HRC, give to the ball bearings the capability of slightly attracted by a magnet with the best corrosion resistance of the standard metals.

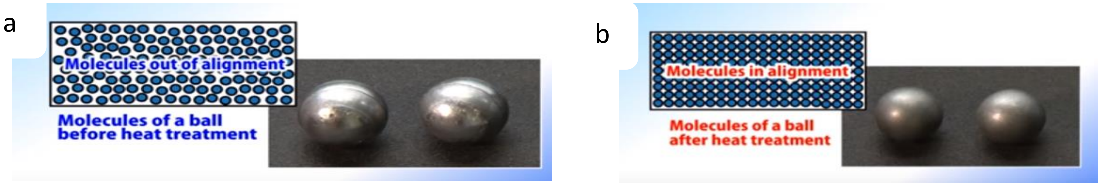


Figure 5. molecules alignment visualization model: a) before Heat treatment b) after heat treatment (19)

3.1.4. Magnetic abrasive finishing

This is a process which may be processed after the heat treatment where the ball closer to the final requirements of its overall precision. The surface finish of the unhardened Stainless Steel Balls encompasses diameter tolerance, roundness shape form and surface roughness which brightens to the human eyes.

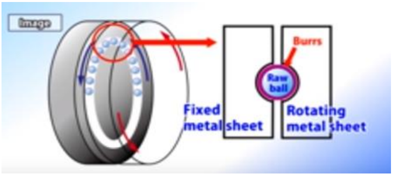


Figure 6. the oscillating motion of steel ball during magnetic abrasive finishing polishing [6]

The carried iron particles and magneto abrasive brushes filmy against the contour surface of the specimen while the operation is in short stroke oscillatory motion in the axial specimen direction and causes the material removal *Ra* with a limited depth of between 10 to 20 nm. The specimen during MAF present surface finish errors and defect such as scratches, hard spots, lay lines, small or large burrs and tool marks. The material removal is enhanced upon input parameters of MAF, specimen material and circumferential speed, the magnetic flux density of the process, working clearance, and size of magnetic abrasive by considering the abrasives used, its grain size and its volume fraction in the composition and the surface finish to achieve. According to *Hassan Abdel*, the axial vibration amplitude, frequency and increase of the magnetic flux density may resulting the best surface finish of AISI 316L ST ball bearings [9] see Table 2.

Table 3. AISI 316L Stainless Steel ball bearings characteristics [20]

<table>
<tr><th>Type</th><th>C</th><th>Si</th><th>Mn</th><th>P</th><th>S</th><th>Cr</th><th>Ni</th></tr>
<tr><td rowspan="15">AISI 316L</td><td>0.03%max</td><td>1.00%max</td><td>2%max</td><td>0.0045%max</td><td>0.03%max</td><td>18.0-20.0%</td><td>10.1-14%</td></tr>
<tr><td colspan="2">Hardness</td><td colspan="3">Ultimate compressive Strength</td><td colspan="2">Service temperature</td></tr>
<tr><td colspan="2">25-30HRC</td><td colspan="3">550-1250MPa</td><td colspan="2">-196/600 ^{0}C</td></tr>
<tr><td colspan="7">Mechanical properties</td></tr>
<tr><td colspan="2">Tensile Strength</td><td colspan="5">90,000psi</td></tr>
<tr><td colspan="2">Yield Strength</td><td colspan="5">45,000psi</td></tr>
<tr><td colspan="2">Elongation in 2 inches</td><td colspan="5">35%</td></tr>
<tr><td colspan="2">Reduction in area</td><td colspan="5">60%</td></tr>
<tr><td colspan="2">Modulus of Elasticity</td><td colspan="5">28,000,000psi</td></tr>
<tr><td colspan="2">Density</td><td colspan="5">0.290lbs/cu.in</td></tr>
<tr><td colspan="7">Physical characteristics</td></tr>
<tr><td colspan="2">Excellent Corrosion Resistance</td><td colspan="3">Austenite stainless steel with low magnetic properties</td><td colspan="2">Authentic material</td></tr>
<tr><td colspan="7">Applications</td></tr>
<tr><td colspan="7">Special bearings, pumps and valves, aerosol and dispenser sprayers, foodstuffs, paper, rubber, military equipment, textile industry, applications in photographic devices, medical instruments, quick couplings, recirculating balls, ink cartridges and jewels</td></tr>
</table>

3.1.5. Cleaning

A cleaning operation removes any processing fluids and residual abrasive material from the machining process.

3.1.6. Visual Inspection

After the primary manufacturing process, every lot of precision steel balls undergoes multiple in-process quality control checks. A visual inspection is performed to check for defects such as rust or dirt, and the process may be done by operators or by means of artificial intelligence method such as circumferential eddy current array (CECA) sensor able to inspect 46,126 steel balls and show a miss rate of ~0.02%, the surface defects of ~0.05 mm in width and 0.1 mm in depth [21].

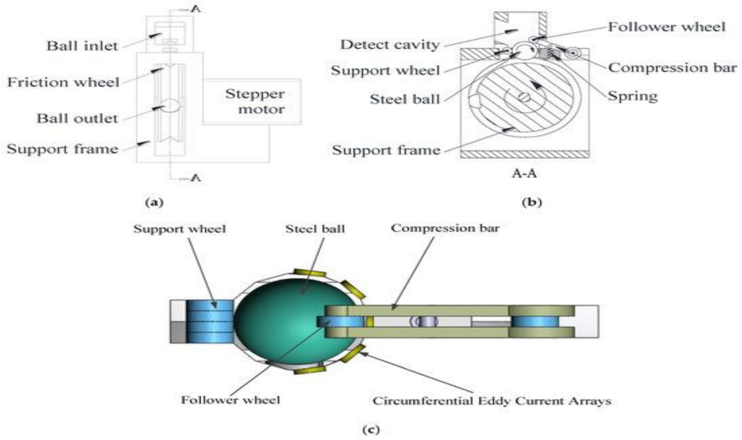


Figure 7. The unfolding mechanism of the steel ball. (a) The main view of the unfolding mechanism; (b) The cutaway view of the unfolding mechanism; (c) The top view of the unfolding mechanism [21].

3.1.7. Roller Gauging

Roller gauging is a 100% sorting process that separates both under-size and over-size precision steel balls.

3.1.8. Quality Control

Each lot of precision balls is inspected to ensure grade requirements of the inputted parameters compared to the output parameters such as diameter tolerance, roundness and surface roughness for input parameters and hardness, strength, accuracy of ball, withstanding forces and any visual requirements are also evaluated for the output parameters, here the Statistical process control is used,[22].

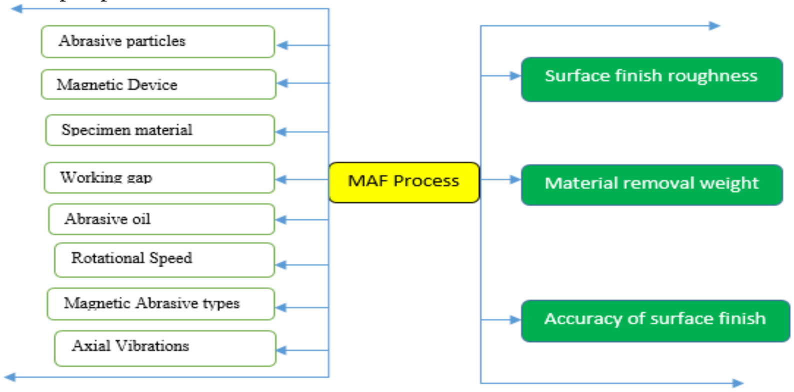
3.2. Effect of input parameters on the Magnetic Abrasive Finishing process

In MAF, the input parameters pay an important effect for the process, according to Singh and Raghuram, 2003 they present two types of forces causing the capability of surface finishing of the specimen and these forces are generated by flexible magnetic abrasive brush or iron abrasive particles. The normal forces provide the packaging of magnetic abrasive particles and causing the micro-indentations into the specimen while the tangential cutting forces lapping the specimen due to the rotation effect of the abrasive material mixture (iron particles) and resulting in the circumferential removal surface material on AISI 316L stainless steel [4]. The abrasive material is a homogeneous mixture of magnetic particles and abrasive particles moving in oscillating motion in the gap between a specimen of AISI 316L Stainless steel and magnet material. Fox et al., 1994, recommend a carefull selection of magnetic particles and abrasive particles because of the difficulties consideration of the gap between the tool and the specimen which is he result of surafce texture and roughness surface control [23].

The process parameter has a significant impact on the Ra and MRR, the output parameters of the MAF process, (see Table 2) and as well as the mechanism of the process. In addition, the detail is given by Biing-Hwa et al. analyze the principle and property of the unbounded machining abrasive particles, Maps on stainless steel SUS 304 with a cylindrical MAF and they have also clarified that steel grit produce superior finishing than that of iron grit when mixed with SiC abrasive and this abrasive silicate is present in the AISI 316L. However, the good finish and accuracy of surface finish with minimum defects or burrs cost effectively while machining with conventional methods such as grinding and polishing. This gives to the manufacturer to integrate the new technology of advanced machining with non-conventional technique including MAF upon the ability to generate:

1. a very high surface finish and accuracy.
2. a very little or no surface damage, such as microcracks to the components during the finishing operation due to the extremely low level of forces.
3. the finishing operation can be significantly faster than by conventional techniques due to the possibility of using higher spindle speeds. [23]

Table 4: MAF input and output parameters, [23]



4. Result and discussion

Relative motion between the magnetic and the abrasive particle mixture and the workpiece is essential for material removal. There are several options for achieving the necessary motion. A common setup is the rotation of the magnetic pole tip. This is done by either rotating the entire permanent magnet setup or by rotating only the steel pole. Another method which is commonly utilized in internal finishing is the rotation of the workpiece, this is unfortunately limited to axial symmetric work pieces. In addition to rotational motion which is oscillatory and vibratory configurations that are applicable and give the magnetic load in the gap or magnetic fields.

$\vec{F} = \bar{V}(\vec{m} * \vec{B})$ (1), magnetic force exerted at magnetic dipole moment in a magnetic field

where

$$m = MV \tag{2}$$
$$M = H_k x \tag{3}$$
$$B = \mu_0 H_\alpha \tag{4}$$

- $\boldsymbol{H_k}$ is the maximum applied field for saturation of the magnetic particle
- $\boldsymbol{H_\alpha}$ is the applied magnetic field intensity
- $\boldsymbol{B}$ is the magnetic flux density
- $\boldsymbol{M}$ is the magnetization of the particle, assumed to be saturated
- $\boldsymbol{m}$ is the magnetic dipole moment
- $\boldsymbol{\bar{V}H}$ is the magnetic field gradient
- $\boldsymbol{V}$ is the volume of the particle (assuming sphere shaped)
- $\boldsymbol{x}$ is the material magnetic susceptibility
- $\boldsymbol{\mu_0}$ is the permeability of free space

By substituting the equation (2, 3 and 4) in equation (1), the magnetic force in a magnetic field will become

$$\boldsymbol{\vec{F} = \mu_0 H_\alpha V H_k x \bar{V}}$$

From the previous study done, according to Thiel et al., 2013, the variation of the surface roughness of the iron particles of 330µm R_{max} for a time of 40 min, the process does not result in a smooth surface when using either a magnetic abrasive only of 0wt% or the iron particles only of 100wt% in the process. Although the MAF process require a conglomerate mixture of abrasive particles to obtain a better surface finish, means the use of 50wt% of iron particles and other ferromagnetic particles with oil may give a smooth surface finish of 0.2µm R_{max} from the initial of inner surface of the spacemen (bottom of tube bomb) was 7µm R_{max} and also there is a correlation between the applied forces, said the finishing pressure and the content of the abrasive which may affect significantly the surface finish, [4]. The difference presented does not give an exact reason for the suitable value of mixed weight percentage of iron particles selected; to finish a better high efficiency smooth surface. Although, this value may depend upon the input and output parameters of the MAF process such as shape, size, the material of the specimen and the finishing conditions. It has found also that the diameter of abrasive particles affects the surface finishing. From the use of 75,330 and 1680µm for a 50wt% as a constant mixed weigh percentage of iron particles present a difference surface finish result and the 330µm give a closer appreciate surface finish in the least amount of time, see Fig 8, [24].

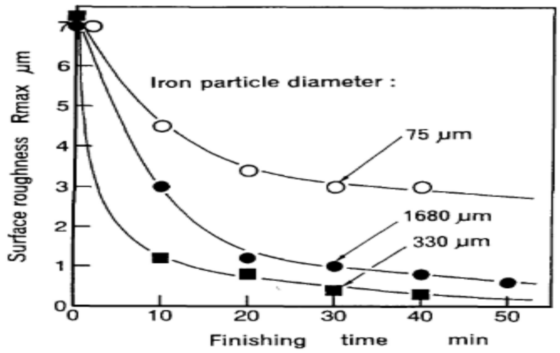


Figure 8. changes in surface roughness with finishing time [Conditions] iron particles diameter: 330μm, [24]

In the gap area between the two poles of magnet and the contour surface of AISI 3016L ball bearing and the area facilitate the oscillation motion of the abrasive particles shows the trend of the curves similar for different working gap values of specimen itself and the highest magnitude of the force is found at lower gap, as long as the gap increases the intensity of the magnetic field crossing along the ball bearing (specimen) hence higher magnetic force is occurs,[4]. According to Singh and Raghuram, 2003, the effect of getting the highest magnitude of magnetic force causes the change in increase value of the packing density of the magnetic abrasive particles used. Consequently, the rigidity of the flexible magnetic abrasive particles changes also its magnetic force by becoaming larger and resulting in deeper microindentations into the specimen, [4, 25]. The needs of nomrmal force (Fn or Fy) is presented during the material removal from the micro-indentation created into the specimen by iron particles (MAPs) combined with the magnetic fieldline. Thus, the cutting force which is Fc or Fx is microchipping the specimen and also the relative movement presented between flexible magnetic abrasive brush (FMAB) and the speciment cause the turning of magnet and speciment in the oscillating motion,[8].

5. Conclusion

The AISI 316L stainless steel has the low magnetic ability and the inputted parameters to the machining process provide a significant effect of this physical property. The axial vibration or oscillating motion and rotational speed have to be controlled since it causes the roughness on the cross section of the tool; the ability that would give the finest surface finish and high removal rate. The recommendation has been given for the process such as a high voltage level, low MAF working gap, the increase and variable of rotational speed, and large mesh number for improving the surface quality. Moreover, the surface finish of AISI 316L stainless steel ball is controlled by the output parameters, Ra and MRR; so that the testing of both parameters has to be tested for being certainly of the obtained micro size indentation or the finished off surface. The proposed method with CECA sensor may be an option for the effective inspection based on its capability to inspecting and detect steel ball surface defects. Although, the interrelation of magnetic force and tangential cutting force cause the change in Ra which is comparatively weak and give a further study. The integrated process such as Magnetic Field Assisted Abrasive Finishing (MFAAF) process tend to machine the best surface finish (Ra) with 0.0766 µm value at the optimal finishing conditions and based on the S/N ration analysis with ANOVA analysis; the normal forces and finishing forces are significantly affected by the high voltage of 22V, low machining gap of 1.5mm, higher mesh size number of 1200 mesh when the rotational working speed is at 540 rpm.

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