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Review of Effect of Burnishing Process on Surface Integrity of Friction Stir Welded Components

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Abstract

Burnishing is a technique of surface improvement that enhances the component's surface finish along with the component's surface properties. It is a cost-effective technique often utilized in the aerospace, biomedical or automotive industries to increase the component's reliability and performance. The response parameters in the burnishing process depend on the burnishing process parameters, the instrument and the burnishing material. Burnishing is a very simple and efficient surface finish improvement procedure and can be done with existing machines, such as shrink.

It also saves money on manufacturing costs due to its high efficiency than other traditional processes, such as super finishing, honing and grinding. In comparison, the burnished surface is extremely resistant to wear and has a longer fatigue life. The burnishing method is an appealing finishing technique that strengthens the work-surface piece's integrity to improve fatigue behaviour under complex loadings.

***Keywords* -** roughness, burnishing, mechanical properties, residual stress

I. INTRODUCTION

Burnishing is an effective and spline less metal finishing process, whereby the roles or balls have a flat surface and depress the asperities of the machined surface. In recent years a lot of attention has been paid to the combustion technique which enhances the surface characteristics of plastic deformation caps. The burnishing method has benefits over other work methods such as grinding, due to the inducible compressive residual stress [1], to ensure improved hardness, corrosion resistance and fatigue life in addition to good surface finish.

The burnishing technique is an enticing finishing technique, which enhances the dignity of the workpiece to promote tiredness under dynamic loads. Burnishing is one of the most critical completion operations usually conducted for increasing fatigue resistance characteristics of the components. Burnishing machines are used to express a polish or a fine surface finish often in operations requiring cold working on metal surfaces. Burnishing equipment is often used for surface scaling and finishing.

By performs a steady planetary rotation of hardened rolls a burnishing instruments build the finished region on the turned or boring metal surface. Rolling rotation raises the development

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point at the moment of effect for the soft metal surface. As in Fig.1 the touch point contributes to the metal surface deformation to create a finished metal surface, and the material in the peaks becomes deformed by plastic and filled into the valleys. Several kinds of burnishing instruments are available. Burnishing does not represent a form of metal cutting.

Burnishing equipment is often used for surface scaling and finishing. An instrument for burnishing a finished surface is created by the continuous planetary movement of hard-rolls on a turned or bored metal surface. The rotating of the rolls raises the output point at impact for the soft metal surface. As in Fig.1 the touch point contributes to the metal surface deformation to create a finished metal surface, and the material in the peaks becomes deformed by plastic and filled into the valleys. Several kinds of burnishing instruments are available. Burnishing does not represent a form of metal cutting.

During the burnishing process, chips are not made. It is effectively a cold formation process in which the metal is displaced near a machined surface by protrusions to replace the depressions. Due to work toughness of the surface during burnishing and the tiredness of the part must be increased; a hardened cover must be on the surface. The burnishing method offers improved resistance to wear and corrosion, in addition to improving the surface finish and the quality of the fatigue [2].

In today's manufacturing sector, particular attention is given on dimensional accuracy and surface finishing. The estimation and characterization of surface roughness can also be viewed as a system performance measure. Burnish is a method that contributes to a slight plastic deformation to accurately change the surface ruggedness of the workpiece. The metal on the workpiece's surface is dispersed in the burnishing process without material damage. In addition to having good surface finishing, the burnishing process provides additional benefits such as enhancing hardness, corrosion resistance and fatigue life as a consequence of the compressed residual stress [3].

The burnishing is also a very good surface finishing technique and the durability of the material's mechanical characteristics. The burnishing surface, in contrast, is highly wear resistant and has a longer life of fatigue. Moreover, thanks to its high performance, it saves on production costs than other conventional methods, including super finishing, processing and grinding. Residual stresses are the crucial element for integrity determination due to their direct impact on service quality, alteration in component output, and life, as service (working) stress is minimized and crack nucleation and propagation is hindered [4].

Take a cautious clean and rough ball to the metal top, and this is a procedure that can be achieved under pressure. The metallic pinnacles of the surface will then extend indefinitely. Amazing residual friction, and then failure consistency and wear barriers to the rise of the surface layer instigate the work piece surface. This will lighten and solidify the surface and make it a systematic solution that would last longer than one which was not crushed [5].

A. Objectives of the Study

1. To establish the process of burnishing and different types of tools used.
2. To study the benefits of friction stir welding in the industry.
3. To investigate the effect of burnishing on different surfaces and material features.

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II. PRINCIPLE OF BURNISHING PROCESS

Burnishing is a flexible method that enhances the finish on the surface and size of the turned pieces, with comprehensive use of equipment. A typical twist, which twists the bits, can be used for burnishing and reduces the time and effort required to remove the workpiece [6] [7]. The burnishing instrument contains one or two balls or rollers, which can be placed in a case. This tool can be placed on the lathe tool post. The friction force rotates the balls or rollers in a planetary movement as the unit is made to come into contact with the spinning portion of the work piece [9].

The DIY approach is used as a cold technique as the workpiece is exposed to intense stress due to planetary motion between the workpiece and the effect of the tool. In case of a strain that exceeds the material production power, plastic motions will respond by reducing the roughness of the surface from the top of the surface to the valleys. This also induces compressive heat residue and long-term stress [10].

In the industry several other types of burnishing equipment are found beside the three primary types of burnishing tools. They are as follows:

- **Ballizing tool**: It is a method of metal displacement in which an overly large ball is forced through a small opening. By transferring a number of materials equal to the interference fit, the ball enlarges the hole. The ball pushes the substance into the plastic flow and leaves an enhanced coating of thick and hardened surface. In certain instances, balls can be synonymously used for burnishing and ballizing. While both processes function under the same structure, the applicability is different. Ballizing shall only be applied when dealing with boreholes where a wide variety of workpieces, including internal surfaces, external surfaces, smooth surfaces etc, may be used as ball burns [11].
- **Burnishing drills:** The drilling procedure is combined with the burnishing process. The front end of the drill consists of a couple of edges radially bent from the middle end of the body forward. The shank that begins after the edges is a few microns higher in diameter than the diameter of the cutting tool. The drilled surface with this shank has a burnishing impact. Until burnishing operations are operational, the configuration of the boiler should provide provision for the removal of chips. The configuration of the boiler looks much like traditional boilers, with the main exception being the height of the shank [12].
- **Diamond burnishing tool**: Diamond burnishing tools are built in a wide range of iron and non-ferrous components to render spiegles like a surface. These instruments are placed into a tool holder with diamonds that can be installed on both traditional and CNC tubes. The high quality insert is coated and contoured to deliver outstanding finishes and excellent lifetime of tools [13].
- **Bearingizing Tool:** The method combines roller burnishing with peening. The tool consists of positions that are rotated at very high speeds, rising and dropping around a truss-cammed arbor. This causes up to two lakhs of quick blows on a workpiece surface

every minute. This allows the surface wrinkles to flatten which contributes to the finishing of very thin surfaces. A bearingizing method as seen in Figure 1.9 [14].

III. BURNISHING PROCESS IN FRICTION STIR WELDING

The Welding Institute (TWI) developed and invented solid-state joining method, friction stir welding, originated as a welding technique to be used in high-strength, hard-to-join alloys using traditional technology. Aluminum alloys were first developed, but after that date, FSW has been found to be ideal for connecting a large variety of materials. In a number of aluminium alloys, including those historically not considered to be weldable, defect-free joints were made with strong mechanical properties. Friction stir welds are not subject to issues such as porosity, segregation of alloys and hot cracking and sold with good surface finish and no post-weld cleaning is required [15].

This welding method requires the advancement of a cylindrical shoulder between two touching sheets of metal by a joint line by a fast spinning pin of rotating hard steel. FSW is a popular new fastening process for the aluminum alloys flat and lap welding. There have been several attempts to understand the impact of process parameters on the material flow behavior and on the creation of microstructures.

Friction stir welding has many benefits relative to traditional arc welding. These comprise:

- FSW is a flawed and unregulated joining mechanism without hot cracking, porosity or fiber cracking as a solid state welding process.
- Since the material is joined together at lower temperatures shrinking and distortion was decreased
- No requirement for the filling of aluminum alloys, flow or shielding gas
- FSW creates no smoke, spreads or UV radiance in the atmosphere.
- Uses machine tool technology to simplify the operation, render the need for professional solderers simple to replay and minimize
- can operate anywhere
- Strong mechanical properties that usually equate or surpass those obtained by competitive processes for aluminum alloys
- Effective electricity
- Able to incorporate several non-silver alloys including 2xxx and 7xxx aluminum alloys
- No need in most applications for special edge planning

IV. PARAMETERS THAT AFFECT SURFACE FINISH

Roughness: It consists of relatively closely-spaced or fine surface irregularities, mainly in the form of feed marks left by the cutting tool on the machined surface. The mean height or depth

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of irregularities is measured over a relatively small length called the roughness sampling length.

Waviness: It consists of all surface irregularities whose spacing is greater than the roughness sampling length (about 1mm). Waviness may be caused by vibration, chatter, and tool and work piece deflections due to cutting loads and cutting temperature.

Lay: It denotes the predominant direction of the surface irregularities. The lay is usually specified with respect to an edge called the reference edge of the work piece. The lay depends upon the orientation of the work piece and the cutting tool on the machine as well as the nature of the relative motion between the two.

Surface Flaws: Flaws could be due to inherent defects, such as inclusions, cracks, blow-holes, etc. in the work piece that get exposed on machining, or they could arise from the machining process.

V. METHODS USED IN FOR OPTIMIZATION OF BURNISHING PARAMETERS

There are several methods used to predict optimized values of burnishing process. Many researchers studied and worked on the optimization methods.

Fang-Jung Shiou et al used Taguchi L18 Orthogonal array technique and ANOVA to investigate the surface roughness value. Best on their results The Vickers hardness scale of the tested specimen was improved from about 338 to 480 after ball-burnishing process. The hardened layer thickness was about 30 µm. By applying the optimal burnishing parameters for plane burnishing to the surface finish of the freeform surface mold cavity, the surface roughness improvement of the injection part on plane surface was about 62.9% and that on freeform surface was about 77.8%.[16]

U.M. Shirsat et al studied the parametric analysis of combined turning and ball burnishing process they used factorial design (23). 23 factorial designs represent eight-experiments, where the experimental points are located at the vertices of a cube shown in Fig. 2. Four experiments represent an added centre-point to the cube, repeated four times to estimate the pure error. The complete design consists of 12 experiments divided into two blocks, each block containing six experiments and one combined block is considered (trial nos 1 to 12)8, 9. This method classifies and identifies the parameters to three different levels (viz. low, center and high). In this experimentation, twelve tests were carried out at these levels.

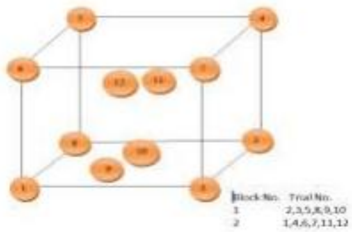

Figure: Composite Design [10]

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For each block the model equations for surface roughness and the surface hardness are obtained by using the analysis of variance technique (ANOVA) and regression coefficient. They develop a mathematical model for obtaining values of surface roughness. The functional relationship between response (surface roughness) of the burnishing operation and the investigated independent variables can be represented by the following equation

$Ra=K*F^{a}*V^{b}*S^{c}$ … (1)

Where Ra is surface roughness (μm), F, V and S are the force (kgf), speed (m/min) and feed (min/rev). [3]

J.N. Malleswara Rao et al worked on finite element approach for the prediction of Residual stresses in aluminum work pieces Produced by roller burnishing. In this work using numerical approach, compressive residual stress is calculated. Roughness is considered as a triangular asperity in this numerical approach. Before burnishing, the height of the triangle is considered as the roughness of the work piece. The normal force is acting on the peak of the asperity. Fig.3 represents the triangular model for numerical approach. The depth of deformed layer depends on the yield strength of the material (σy), normal load (Fn), and the asperity angle (α)

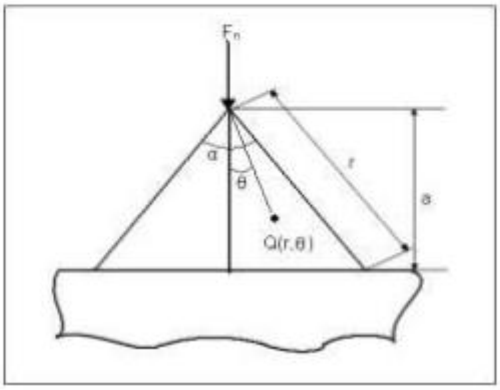

Figure: coordinates of a point Q (r, θ) within a triangular asperity [17]

VI. IMPROVED MECHANICAL PROPERTIES OF MATERIALS

- **Ductility**

Khalid. S. Rababa et al, studied Effect of roller burnishing on mechanical behavior and surface quality of O1 Alloy steel, it was seen that there was a slight increase in ductility at 105 N force but there was a 76.6, 103.3, 113.3% increasing ductility at 140,175,210N burnishing force. [18]

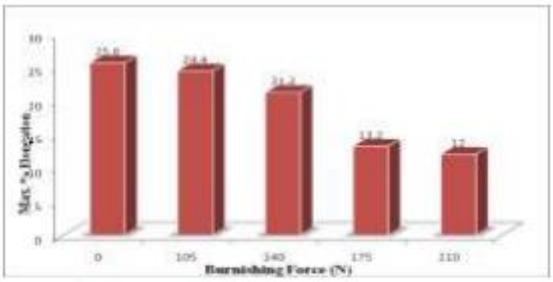

Figure: Max. % Elongation vs. burnishing force

- **Residual stress**

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Fathi Gharbi et al studied the distribution of compressive residual stresses by ball burnishing process. It was observed that the residual stresses are compressive with low values between 0 and -45 MPa. It is observed that in the feed direction, burnishing normal load has an influence on the affected depth corresponding to the optimum value of the residual stress σxx , When the normal load increases from 100 to 200 N for the same ball diameter (10 mm), the affected depth increases from 40 to 110 µm, respectively, for an optimum value of σxx - 30 and -45 MPa, at 110 µm and the optimum value of the residual stress σyy is Equal to -30 MPa.[19]

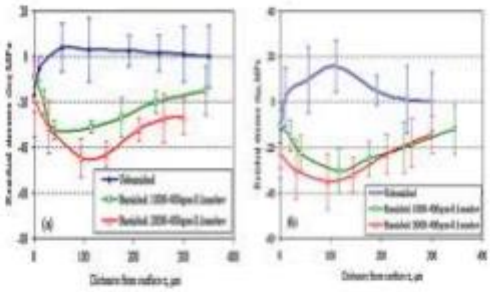

***Figure: Residual stress profiles measured from surface: in the feed direction, σxx (a), and in the cross-feed direction, σyy (b)** [18]*

- **Tensile strength**

Fathi Gharbi et al studied the effect of ball burnishing process on tensile properties of material.

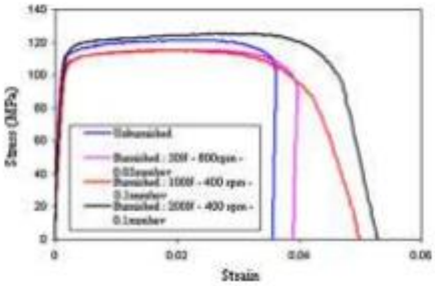

***Figure: Stress–strain curves of tensile tests for burnished and unburnished specimens**.[17]*

It was seen that the tensile test curves for cold-rolled aluminum 1050A for different burnishing conditions are illustrated in Figure above. As shown in Figure above, burnishing aluminum 1050A plates can have a significant effect on its stress– strain behavior. The stress–strain behavior for aluminum 1050A remains more or less constant in the plastic zone. Depending on the burnishing force, the yield strength and the ultimate tensile strength may decrease or increase as compared with the unburnished condition. Fig.9 also shows that the plasticity increases with no increase in the stress. Both the energy and percent elongation at fracture increase with burnishing. [20] studied Effect of roller burnishing on mechanical behavior and surface quality of O1 Alloy steel, it was seen that It can be seen from Fig. 15that by increasing the burnishing force (BF), UTS will increased until burnishing force reaches (105N).

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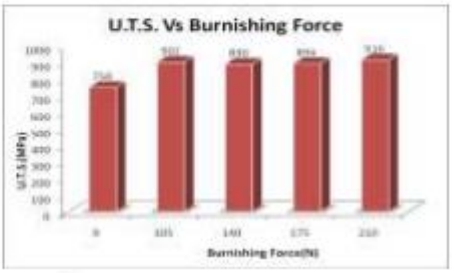

- **Hardness**

Adel Mahmood Hassan studied the effect of ball and roller burnishing on the surface roughness and hardness of some non ferrous metal. It was seen that the surface hardness of a material is increased with increase in burnishing force and number of burnishing tool passes. [21]

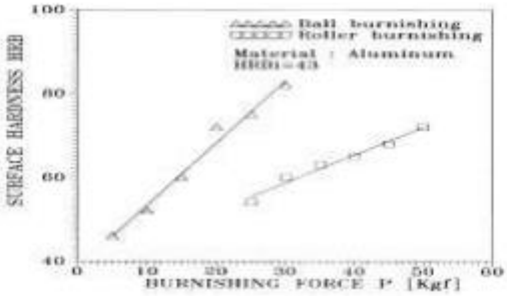

Figure: The effect of burnishing force on surface hardness of aluminum

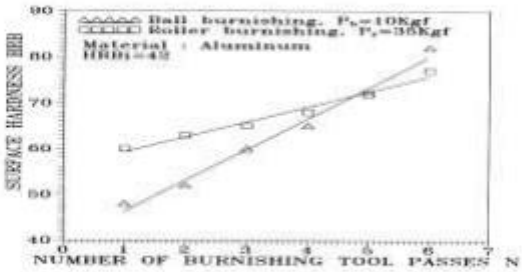

Figure: The effect of the number of burnishing tool passes on surface hardness of aluminum

Malleswara Rao J.N et al studied the effect of roller burnishing on surface hardness and surface roughness on mild steel specimen, based on the works it was observed that the surface hardness increases with increasing burnishing force. This is mainly due to increased plastic deformation of micro irregularities with high burnishing force.[22]

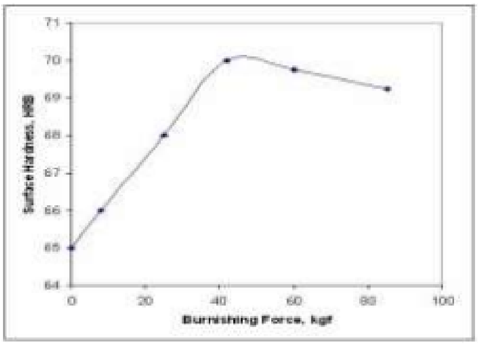

Figure: burnishing force verses surface hardness. *[22]*

VII.REVIEW OF LITERATURE

Malleswara Rao et al (2011) developed the Finite Element approach to predict waste stress in roll burnishing aluminum parts. Compressive residual stress is measured in this work using numerical method. In this numerical method, rughness is shown as a triangular asperity. The hight of the triangle is known as the ruggedness of the workpiece before fire. On the height of asperity the natural force is acting.The method is modeled on the surface ruggedness of 2 D FEA and is called a triangular asperity with an α angle equivalent to 800. The triangular asperity of the surface is known to be rough before burnishing [25].

EL-Tayeb et al (2011) implemented the prediction of surface completeness with the radial function . They employed surface roughness prediction techniques using an artificial neural network (ANN) and RBF system. Artificial neural networks are the computational components which concentrate on the structure and function of biological neurons. In these networks there are neurons or nodes that are differentiated. The nodes are interconnected or interconnected layer precisely. The internal product syneaptic weights are received with the node outputs in the previous layer, as the binary or bipolar hard restricting nonlinearity is used on each node in the subsequent layer. If the vectors are analog [26], a squashed function is used.

In order to explore the pitting and mechanical properties of oxidizations of static steels, Mukhanov (2012) submitted the results of ultrasonic burnishing. The effects of burnishing on wear strength and plasticity impacts have also been studied. Rogozhkina and Azorkin, however, have studied the effects on static strength and fatigue of locomotive steels by systemically performed burnishing experiments. Their research also sought to measure briefly the results of the number of burns [27].

Khvatov (2010) has been investigating the effect on the sealing properties of pairs of seals made for pneumatic cylinder of the form and structure of the micro-rawliness of piston rods. In order to improve operating characteristics of multiple pairs of friction surfaces, Barsegyan has developed a technical method for vibro burnishing with due consideration for the oil potential of the surfs. Vibro burnished surfaces have an oil potential which can be calculated by geometric parameters of the extruded surfaces [28].

The fatigue resistance of the surface-reinforced plastic deformed plastic pieces of different size and built of different steels is studied by Belkin (2016). For the test component thickness, the optimum burnishing force that raises the fatigue limit increases. The ideal intensity also depends on the test component content. By applying peening operations [29], the effect of reinforcing the plane's large-sized sections can be amplified.

Mitryaev & Seryapin (2009) investigated the effect of plastic deformation surface strengthening on titanium alloy VT 9 fatigue resistance with a V-shaped notch, and formed relationships with residual compressor stress bars dissemination and degree to fatigue resistance to destruction in the concentration conditions. The fatigue limit of smooth specimens rises by 14 percent and 10 percent relative to polishing, the strengthening of burnishing and blasting procedure Pleiman spoke about carbide advantages – burnishing of rollers. There has been mention of the better efficiency and competitiveness of roller burnishing [30].

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The rough rolling burnishing operation was studied by Klocke and Liermann (2014). A hydrostatically born ceramic ball rolls under intense pressures over the part surface during a rough roll burnishing process. The peaks of ruggedness are flattened and the surface consistency of the piece has increased. This method offers a production option to grind and finishing operations in combination with rough turning [31].

In the multipurper burn system on square titanium alloy cloth, Thamaizhmnai et al (2008) measured different speed/speed, feed rate and penetration depth [33].

The vertical machining center for AISI 1045 steel material was investigated in ball burnishing phase by Loh et al (2013). The research technique and the F-test were employed to detect a major influence on the surface roughness of the ball material, lubricant, feeding and penetration depth [34].

The ball burnishing tools of aluminum and metal components were produced by Hassan and A1-Bsharat (2015). The surface ruggedness, toughness, tension, tensile strength and tiredness were examined before and after burnishing. As a consequence, the above mentioned properties have been enhanced due to the method of burnishing [35].

Esme (2010) studied the multi-response optimisation of the burnishing mechanism for an optimum parametric combination with a Gray relational analysis and Taguchi approach to achieve desirable surface ruggedness and micro toughness. Seventeen test runs based on the Taguchi orthogonal array have been conducted to achieve objective functions for optimisation within the experimental sector. Goal feature in relation to burnishing parameters: burnishing power, number of passes, feeding rate and burnishing speed were chosen. In order to overcome the multi-intervention optimization problem, the Taguchi method followed by Gray relation analysis was applied. The impact of the variables on overall quality features of the burnishing process was also quantitatively assessed using the variance technique (ANOVA). Confirmation tests have confirmed optimum outcomes [37].

Prabhu et al have investigated the roughness and hardness of surface aspects of the working material of AISI 4140, using the experimental fractional factorial design. The effect on the surface of surface ruggedness and toughness of AISI 4140 steel were measured for both the LPB and Deep Cold Rolling (DCR) processes and comparison was carried out [40] of key process parameters (force, feed rate, tool transfer / execution, initial piece of roughness, ball material, ball diameter and lubricant) [38].

A comprehensive literature review was undertaken by the researcher to study application of burnishing process on friction stir welding and investigation of the effect of burnishing process on the surface roughness, hardness, corrosion resistance, fatigue strength and residual stress incorporating various studies. This comprehensive review was focused on existing peer-reviewed papers that were freely accessible.

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Sr. No.	Topic	Result	Author
1.	Evaluation of optimum values of surface roughness on Al work piece using roller burnishing	The study found that Roller burnishing produces better and accurate surface finish on Aluminum work piece in minimum time. Roller burnishing is an economical process, where skilled operators are not required. This process can be effectively used in Aerospace technology applications and to finish Aircraft components.	Malleswara Rao , J.N. Chenna Kesava Reddy , A. and Rama Rao, P.V. (2011)
2.	Prediction of burnishing surface integrity using Radial Basis Function	Study concluded that the process state variables used were burnishing speed, feed, and depth. RBF has achieved a minimum of 90.62% of prediction and proved to be convenient in terms of least computational complexity and dealing with nonlinear data such as obtained in this work.	EL-Tayeb, N.S.M. and Purushothaman, S. (2011)
3.	Structure and Mechanical Properties of Friction Stir Weld Joints of Magnesium Alloy AZ31	It is found that both anodizing treatment and insertion of aluminum foil between batting faces do not degrade the joint properties at all. The results suggest that friction stir welding can be potentially applied to magnesium alloy.	Mukhanov, G. (2012)
4.	Application of burnishing process on friction stir welding and investigation of the effect of burnishing process on the surface roughness, hardness and strength	The study results of surface roughness and surface hardness values show that increasing the compression force increases the surface hardness while surface roughness becomes worse after a certain force value. It is also found that increasing the	Khvatov (2010)

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		feed rate increases the ultimate stress and increasing the pass number causes to increase the crushing rate of the material and results in a micro crack formation at the welded region.	
5.	The effect of ball and roller burnishing on the surface roughness and hardness of some nonferrous metal	The results show that improvements in the surface roughness and increases in the surface hardness were achieved by the application of both ball burnishing and roller burnishing with the non-ferrous metals under consideration.	Belkin (2016)
6.	Effect of Burnishing Process on Behavior of Engineering Materials- A Review	The study concluded that surface of the material is progressively compressed, then plasticized as resultant stresses reach a steady maximum value and finally wiped a superfine finish. The highly finished processes find the application in aerospace and aircraft industry.	Mitryaev and Seryapin (2009)
7.	Roller Burnishing of Hard Turned Surfaces	The study evaluated that structure analyses and residual stress measurements were used to examine the effects of the process on the workpiece surface zone. Hard roller burnishing transforms tensile residual stresses present in the surface zone after hard turning into compressive residual stresses. Hard roller burnishing has no effect on the formation of white layers in the surface zone.	Klocke, F. Liermann, J. (2014)

8.	Surface Improvement Using a Combination of Electrical Discharge Machining with Ball Burnish Machining Based on the Taguchi Method	Experimental results indicate that the combined process effectively improves the surface roughness and eliminates the micro pores and cracks caused by EDM. Therefore, the combination of EDM and BBM is a feasible process by which to obtain a fine-finishing surface and achieve surface modification.	Lin, Y. C. Yan, B. H. and Huang, F. Y. (2001)
9.	Surface roughness investigation and hardness by burnishing on titanium alloy	The roller burnishing is very useful process to improve upon surface roughness and hardness and can be employed. It will help to impart compressive stress and fatigue life can be improved. The titanium alloy is a difficult to machine material and burnishing is difficult process for this grade material. A low surface roughness and high hardness was obtained for the same spindle rotation, feed rate and depth of penetration.	Thamizhmnaii, S. Bin Omar, B. Saparudin, S. and Hasan, S. (2008)
10.	Use of response surface methodology to optimize the finish in ball burnishing	The empirical and experimental results agree reasonably well, deviating by about 2.8%. For each set of burnishing conditions, an optimum depth of penetration and feed for giving the best surface finish is clearly evident.	Loh, N. H. Tam, S. C. and Miyazawa, S. (2013)

VIII. CONCLUSION

In burnishing process, the material is plastically deformed to produce highly finished surface. There is no material removal in this process; surface finish is obtained due to plastic deformation of the material. Burnishing force and number of burnishing tool passes are the

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important parameters to improve the ductility of materials. Burnishing process greatly affects the frictional coefficient and improves wear resistance of materials. Different methods can be used effectively for obtaining optimum parameters for burnishing process. Wear resistance can be improved after burnishing process. As compared with other surface finishing processes burnishing can give better surface quality and dimensional accuracy.The stiff ball/roller burnishing tool can open a new direction for burnishing process. In stiff ball burnishing based on the initial surface roughness of the material, depth of penetration of the tool can be decided, and it will be independent of material.

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