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Investigation In Wire Electric Discharge Machining (Wedm) Of Titanium Alloy (Ti-6al-4v) For Biomedical Applications - Review

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***Abstract*:**Ti-6Al-4V (grade 5 titanium alloy) material is commonly used for biomedical applications especially in dental implants. Titanium alloys are some of the recently developed advanced materials having tremendous mechanical properties including high yield strength, high strength to weight ratio and excellent in biocompatibility. Titanium alloys having poor machinability and not able to machine in conventional machining process. These alloys can be machined effectively using some unconventional machining methods. Wire-Electro Discharge Machining (WEDM) is one such advanced machining technique working to machine intricate shapes like hardest metals like titanium. The objective of the study is to investigate and identify the optimal process parameters in electric discharge machining of Ti-6Al-4V. The machining parameters such as voltage, discharge current, pulse on time and pulse off time are considered as input parameters and material removal rate (MRR),tool wear rate (TWR) and surface roughness (Ra) are considered as response parameters. The design of the experiment strategy was followed by selecting the Taguchi optimization technique (L9) to optimize the process parameters. By analysis of variance, the most influential parameters will be found for wire electric discharge machining process.

I INTRODUCTION

The non-traditional thermoelectric procedure called "electric discharge machining" removes material from the work piece using a sequence of small sparks. One such technology that is frequently used to manufacture materials that are electrically conductive is EDM. EDM is a thermo-electric method that involves carefully managed spark production to move material. It is one of the most widely utilised non-traditional machining techniques today. EDM is typically employed in the production of surgical, automotive, and aerospace components, as well as in the mould and die business. Fragile components can be machined without the danger of damage since there is no mechanical contact between the tool and work piece.The term "titanium alloy" refers to alloys that combine titanium and other chemical elements.. These alloys are extremely great tensile strength. They can sustain extremely high temperatures, have exceptional corrosion resistance, and are lightweight. Because to the high cost of both raw materials and production, its use is only permitted in consumer electronics, military applications, bicycles, medical gadgets, jewellery, etc.Titanium is frequently alloyed with relatively small amounts of vanadium and aluminium, approximately 6% and 4% by weight, for the majority of applications, even though "commercially pure" titanium has been used for orthopaedic and dental implants and possesses the necessary mechanical qualities.

Being an alloyed titanium, titanium Grade 5 is regarded as an alpha-beta alloy. Ti 6Al-4V is the popular name for Titanium Grade 5, an alloy of titanium with 6% aluminum and 4% vanadium. Titanium Engineers offers titanium Grade 5 machined parts, seamless titanium tube, and titanium bar.Titanium has the best strength to weight ratio of any metal and is extremely resistant to chemical assault. Because of these special qualities, titanium may be used in a variety of applications. Because of its stiffness to weight ratio, which is comparable to steel, it can be utilised as a replacement where weight is a key factor. Additionally, it is biocompatible, making it ideal for medical applications since it is nontoxic and capable of Osseo integration. Ti 6Al-4V might benefit from heat treatment to make it stronger. This is particularly evident in aviation, where its usage in compressor fans and landing gear has significantly improved thrust to weight ratios. Titanium is extremely recyclable, which lowers the production costs. Because of its inertness, which allows it to withstand weathering, it has a lower lifetime cost than other metals used in architecture and construction.

II LITERATURE REVIEW

Shubhang G Kadadevarua and Vinayak N KulkarnibOne such important property of a biomedical alloy is its surface integrity as the parts of human body are always in touch with the surface of such materials which may be implants, surgical devices,etc. This review article focuses on studying the effects of process parameters of various manufacturing processes on the surface integrity in biomedical alloys and will try to identify the areas of work to be focused to produce better results. [1]

Mohamed Boujelbene et al.The main purpose of this experimental investigation is the optimization of the surface integrity of work pieces made of Ti-Al intermetallic composite, designed with the combination of thixoforming method and semi-solid powder metallurgy, when they are machined by laser cutting. [2] D. Avinashet al.While the secondary aim of this research is to investigate the effect of process parameters on fatigue strength of titanium (grade-2) alloy. During fatigue test it was observed, fatigue strength decreases with an increase in current and pulse on time.. [3] H.R. Basavarajuet al. The effect of interaction factors, such as peak current, pulse on time, pulse off time has been examined utilizing each factor in time technique.[4] Bassam Khanet al.Ti-6Al-4V alloy as one of the best biocompatible materials for producing biomedical implants, suitable with tissues inside the human body. [5]K.Tamil Mannanet al.The experimental results reveal that the kerf width increases as the pulse on time, input power, server voltage and wire tension increases and the MRR increases as the pulse on time and input powerincreases. It is observed that as the pulse on time and input power increases, the surface roughness also increases. Further it is observed that as and when the wire tension and servo voltage increases the surface roughness decreases and it improves the quality of machined surface.[6] Mahendra U. Gaikwadet al.A research is to investigate the effect of process parameters on fatigue strength of titanium (grade-2) alloy. During fatigue test it was observed, fatigue strength decreases with an increase in current and pulse on time.[7] Narender Singhet al.A review the different research work and effect of various input parameter on performance measures during micro-machining of Titanium alloy is reported.[8] G. Surya PrakashRaoet al. (Linear regression for efficient titanium machining is used to test statistical models relating to the machining efficiency. This will be used to obtaining the best input parameter for MRR and Ra.[9] M. Manjaiahet al.The optimization results of WEDM of TiNi also indicate that pulse duration significantly affects the material removal rate and surface roughness.[10]

Muhammad P. Jahanaet al.The surface micro hardness increased in both NiTi and Ti-6Al-4V work pieces after micro-EDM due to the formation of the oxide layers.[11] sandeep singhalet al.This state of the art review has been conducted to identify recent research on machining of titanium alloys using WEDM[12].Sanghamitra Daset al.This paper reports an experimental investigation on the measurement and analysis of molybdenum wireerosion after WEDM of Ti-6Al-4V alloy at varying input levels viz[13]. Binoy Kumar Baroiet al.The optimum condition for each response has been evaluated by analyzing the effect of input parameters on the mean of the responses[14]. S.M. Haoet al.The wire-EDM induced microcracks extensively happen on the EDM-cut surface and penetrate into matrix up to 10–30 mm[15].A. Pramaniket al.The fatigue performance of all samples is very similar at higher cyclic loading. The machining conditions affected the lower cyclic loading.[16] A. Mahamaniet al.The analysis of the result indicates that the machining parameters have significant influence on the responses[17].FarnazNourbakhshet al.The objective is to investigate the effect of seven process parameters including pulse width, servo reference voltage, pulse current, and wire tension on process performance parameters[18].Rajesh KumarPorwal et al.A optimization of different performance characteristics with alteration to input parameters through employment of technique[19] A. Pramanik et al.To deepen the understanding in this area, this study investigates surface generation, kerf width, discharge gap, Material Removal Rate and wire degradation during WEDM of Ti6Al4V alloy[20].

III CONVENTIONAL MACHINING

Conventional machining techniques, commonly referred to as classic machining techniques, are where material is removed by making contact between the tool and the workpiece while moving either. Traditional methods include drilling, milling, turning, and grinding, among others. The standard machining operations without good process control aren't helpful in attaining greater surface integrity and may even hurt the surface integrity if wrong methods are used, according to a review of many literatures. The surface integrity is greatly influenced by the tool's material, geometry, alignment with the workpiece, cutting speed, feed, cooling fluids, etc.Ball end milling is one of these traditional methods because it can produce smooth, 3D shapes. In Ti6Al4V, a commonly used titanium alloy with biomedical properties, Kaway and Zhang used this process of ball end milling to study the impact of cutting speed, feed rate, and depth of cut on surface integrity. They found that the depth of the deformation at the subsurface beneath the milled surface increases along with an increase in cutting speed, feed rate, and depth of cut.

The alloy is used for orthopaedic applications, and researchers studied the impact of end milling process parameters on AISI 316L stainless steel with coated tungsten carbide tools (TiAlN), stating that their experiments were aimed at determining the relationships between hardness, surface roughness, and process parameters, specifically cutting speed & feed rate. They discovered that surface roughness (Ra)it rose with increased feed rate and reduced with increased cutting speed, but the hardness of the machined surface is proportional to the cutting speed and feed rate. It was determined that an implant with a low surface roughness would be less likely to fail mechanically or chemically, while one with a high hardness would be able to delay early failure.reported findings on dry and little lubrication in casting magnesium alloy drilling (AM60). It was discovered that surface roughness values varied depending on how many holes were generated in different drilling conditions. The drill failure started at a surface roughness value of 46.8 - 25.3 m when drilling was in a dry state. Also, it was shown that the use of H2O-MQL (minimum quantity lubrication) in drilling led to increased surface roughness.

Even if standard machining may be used, it needs extra attention to achieve the necessary surface integrity, such as cooling fluids, temperature management, post-machining treatment, etc. Because certain alloys, like Nitinol (Nickel-Titanium), work harden quickly, traditional machining can be difficult with these materials. Owing to unique characteristics, excessive stress during conventional machining causes the hardness of the machined surface to rise in Nitinol alloys. Temperatures on the work material's surface, the formation of a white layer, significant stresses, high strain rates, high cutting force, surface flaws, extreme hardness, and the emergence of microcracks are the primary issues with conventional machining of nitinol.In order to get improved surface properties in smart alloys like Nitinol, conventional machining would also result in excessive tool wear, burr development, and unfavourable chip formation. In biomedical alloys, maintaining the properties is a very important factor. Because nitinol is a shape memory alloy, it cannot be subjected to machining processes that are vulnerable, such as conventional processes, so non-conventional machining sources can be used to achieve better accuracy and surface integrity.

The primary distinguishing feature of conventional machining is the cutting tool's direct contact with the work piece. Turning, milling, and drilling are some of the several machining processes that fall under this category. These processes can be carried out in dry or wet environments. Other variations of these procedures include ultra-precision machining, micro milling, face milling, planar milling, angular milling, horizontal drilling, and directional drilling, to name a few. The many cutting parameters that were taken into consideration for Ti-6Al-4V were primarily researched and are equally mentioned. While the machining conditions are different, the parameters for these procedures are identical.Researchers have frequently looked at how variables including depth of cut, spindle speed, spindle power, cutting material, speed, and feed rate affect machinability indicators like tool wear rate, chip formation, and work piece surface roughness. Comparison of the outcomes is challenging because of the variations in the machining circumstances.

One of the current standard procedures in conventional machining is to cut titanium at a slower cutting speed but with a deeper cut. Due to this, it is difficult to produce goods at the customary high rate that can be achieved in the machining of steel. The main problem encountered while machining titanium-based alloys with any of the normal machining procedures has been observed to be damage to the work piece and cutting tools.Different conditioning of the work piece or tool was carried out in order to reduce tool wear rate, enhance work piece surface integrity, comprehend main causes for tool wear, and establish ideal parameters for particular machining operation. Using lubricant was part of the conditioning strategy. Cryogenic cooling, intermittent cutting, laser or plasma heating, or a combination of two or more of these conditions. In addition, cutting tool performance in use for both old and new modifications was assessed.

IV NON CONVENTIONAL MACHINING

These procedures include laser beam machining, water jet machining, electric discharge machining (EDM), wire electric discharge machining (WEDM), etc., where material is removed without the workpiece or tool coming into touch. Surface integrity depends on the mode and process control methods. For Ti-based and Nitinol materials, the WEDM & EDM process parameters are a crucial factor in producing a superior surface quality. Some of these procedures several scholars have addressed and underlined the impact of certain factors, such as pulse on time, pulse off time, spark gap voltage, etc. Along with these, there are additional process variables including wire feed, table feed, and dielectric medium.Nitinol vascular stents' surface integrity was statistically characterised by fibre laser cutting. Important findings from Fu, Liu, and Guo's study included I Narrow and consistent kerf was attained thanks to the fibre laser's superior beam quality. (ii) The recast layer's hardness is lower than that of the bulk material, and microcracks have also been seen there. (iii) Compared to laser power, laser cutting speed had a far greater impact on surface integrity. The surfaces of regulated quality may be produced by multi-mode (milling, countersunk holes, straight cut) machining of NiTi SMA, according to Kong et al. (2013) who researched the surface integrity and geometrical accuracy in multi-mode AWJM of Nitinol SMA.Also, it was observed that the workpiece had no white coating, fissures, or distorted structures. The process parameters standoff distance and abrasive flow rate were discovered to be the most significant parameters on the surface roughness in the case of AWJM as researched by Vasanth S et al. on Ti6-Al-4V. When using a higher abrasive flow rate with a higher standoff distance, more material has been removed from the workpiece. Standoff distance is all about the mechanical force being applied to the workpiece, and if it is higher than the ideal levels, it could result in the formation of large craters on the worked surface.

The use of distilled water as the dielectric liquid resulted in lower surface roughness, which was associated with fewer microcracks and the specimen displayed high corrosion resistance, according to research on the effect of the dielectric liquid during EDM machining of 304 austenitic stainless steel. This article discusses the significance of the employed dielectric liquid, which is crucial since it shouldn't in any way compromise the alloy's biocompatibility. Aluminum electrodes are discovered to have better surface finishes than graphite or copper electrodes in EDM, according to A.Hascalik et al. and this emphasises the fact that even electrode materials play a key role in determining surface integrity and there are a variety of factors to consider.There are many options for electrode materials, but copper, aluminium, brass, graphite, and some combinations, such zinc-coated brass and copper, are the most often used ones in both EDM and WEDM processes. S.L. Chen et al. observed microcracks on the EDMed surface of Ti6Al4V using distilled water as the dielectric liquid. These micro cracks are seen in distilled water primarily due to the high cooling rate & thermal conductivity of the dielectric liquid as compared to other dielectric liquids like kerosene, where there were more noticeable cracks noticed in the machined surface. From the perspective of surface topography, it is discovered that at 50% duty factor, the surface has more peaks and valleys, which may be caused by increased temperature.

In the case of WEDM, the servo voltage, pulse on time, and pulse off time are thought to be the key process variables that affect the surface integrity. According to research done on TiNiCo alloy by Soni et al., high pulse on time significantly increased the amount of fractures, microglobules, and huge craters that appeared on the surface of the specimen as compared to specimens machined at low pulse on time. This suggests that the short pulse on time may help to preserve the necessary surface properties. Moreover, it was discovered that the white coating is thicker at high pulse on time and low servo voltage than it is at lower pulse on time and higher servo voltage.In WEDM machining of Ti-6Al-4V, Arikatla et al., looked at the impact on surface integrity during main and trim cuts. They noticed that the rough cut/main cut surface has moderate to large peaks and valleys, micro holes, craters, black patches, and surface cuts, but the trim cut surface has very few and small surface cuts. Also, it was discovered that the thickness of the recast layer is greater during main/rough cuts and less so during trim cuts. The greater temperature is made possible by the longer pulse length, which produces more molten material and creates room for a thicker recast layer. The proportion of carbon in the wire EDMed surfaces is high for the main/rough cut and low for the trim cut, according to EDX analysis.In order to machine Nitinol smart alloys, Vinayak et al. studied the impact of three key WEDM parameters, including pulse on time (TON), pulse off time (TOFF), and spark voltage (SV), and discovered that TON and SV are the main contributing factors. They also reported that Surface Roughness (Ra) increases with TON while decreasing as TOFF and SV increase. Lower TON with greater TOFF and lower TON with higher SV values are favoured for reducing surface roughness.

Residual strains are caused by the machined surface's uneven temperature distribution and the quenching action of the utilised dielectric fluid. Many studies have demonstrated that the existence of uncontrolled residual stresses causes changes in characteristics as well as early breakdown of the material. The residual stress alters the microstructure of the material being machined. Brass wire produces more residual stresses than copper wire with a single layer of zinc coating or double layer wires when used in WEDM.The fatigue life of components is being shortened by residual stresses, thus settings or combinations that cause this should be changed or avoided since it is a crucial criteria for biomedical applications. The thermal stresses caused during machining, particularly at high pulse on durations when there would be more prominence of thermal stresses, are what cause the fractures to appear on the WEDM surfaces. Heat treatment techniques can be used to lessen or eliminate the low fatigue strength displayed by specimens with widespread residual stresses.

V CONCLUSION

In addition to discussing the types of alloys used and their applications, this review article provides a thorough analysis of the findings of several researchers in the field of machining biomedical alloys, whether through conventional or unconventional modes. the properties of some of the most commonly used materials have also been tabulated well. in this article, various approaches employed by the researchers are presented. the contributions have also been presented, and several research gaps have been noted. a significant number of materials have not been examined or studied for their performance during conventional machining,

REFERENCES

1. Shubhang G Kadadevarua,*,Vinayak N Kulkarnib ,V.N.Gaitondec, “A Review on Surface Integrity Studies in Machining of Biomedical Alloys” Materials Today: Proceedings 18 (2019) 5494–5501
2. Muhammad P. Jahana , Pegah Kakavand, Farshid Alavib, “A comparative study on micro-electro-discharge-machined surface characteristics of Ni-Ti and Ti-6Al-4V with respect to biocompatibility” Procedia Manufacturing 10 (2017) 232 – 242
3. S. P. Leo Kumar1& D. Avinash2,*, “Investigations on Surface Morphology Micro-milling of Ti-6Al-7Nb Alloy form Biomedical Applications” ISBN: 978-93-80689-28-9
4. H.R. Basavaraju , R. Suresh b, S.S. Manjunath and L. Janardhan, “Study on effect of process parameters on MRR and surface roughness in wire electrical discharge machining of titanium grade 7 alloy” Materials Today: Proceedings 18 (2019) 5494–5501
5. Bassam Khan , Rahul Davis b, Abhishek Singh b, “Effect of input variables and cryogenic treatment in wire electric discharge machining of Ti-6Al-4V alloy for biomedical applications” Materials Today: Proceedings
6. Siva Prasad Arikatlaa K.Tamil Mannanb and Arkanti Krishnaiahc “Parametric Optimization in Wire Electrical Discharge Machining of Titanium Alloy Using Response Surface Methodology” Materials Today: Proceedings 4 (2017) 1434–1441
7. U. Gaikwad and A. Krishnamoorthy a, Vijaykumar S. Jatti b, “Investigating the influence of electrical discharge machining process parameter on fatigue strength during machining of titanium grade-2”
8. Narender Singh ,Pushpendra S. Bharti, “A review on micro electric discharge machining of titanium alloys” Materials Today: Proceedings
9. Shubhang G Kadadevarua,*,Vinayak N Kulkarnib ,V.N.Gaitondec, “A Review on Surface Integrity Studies in Machining of Biomedical Alloys” Materials Today: Proceedings 18 (2019) 5494–5501
10. Shubhang G Kadadevarua,*,Vinayak N Kulkarnib ,V.N.Gaitondec, “A Review on Surface Integrity Studies in Machining of Biomedical Alloys” Materials Today: Proceedings 18 (2019) 5494–5501