

Characterization study in ZE41 Magnesium Alloy using Abrasive Water Jet Cutting

Submitted in partial fulfillment of the requirement for the award of
Bachelor of Engineering degree in Mechanical.

Project carried out by

P.N.PREM (39150101)

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DEPARTMENT OF MECHANICAL ENGINEERING

SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **P.N.PREM(39150101)**, **S.RABIN (39150103)** who carried out the Project entitled "**Characterization study in ZE41 Magnesium Alloy using Abrasive Water Jet Cutting**"

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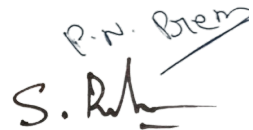
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Declaration

WE **P.N.PREM (39150101)** **S.RABIN (39150103)** hereby declare that the Project Report entitled “**Characterization study in ZE41 Magnesium Alloy using Abrasive Water Jet Cutting**” done by me under the guidance of **Dr.RAM PRKASH** at Sathyabama University is submitted in partial fulfillment of the award of Bachelor of Engineering degree in Mechanical.

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ABSTRACT

.... ZE41 is a magnesium alloy is used in heat exchangers, condensers, reactors, and pressure vessels where good surface qualities are required. The current research focuses on the striation zone (SZN), striation angle (SA) and Surface roughness (SR) in ZE41 is a magnesium alloy using Abrasive Waterjet Cutting (AWJC). The significant variables in the investigation were abrasive water jet pressure (AWJP), traverse speed (TS), mass flow rate (AMFR), and stand-off distance (SOD). According to Taguchi's L18 orthogonal array, the responses for each cut test were created. In addition, the principal component-based grey incidence (PGI) technique successfully combines the strengths of both the optimization tool to identify the ideal parameter condition. The confirmation results revealed that the PGI technique improved SR by 4.02%, SZ by 6.67%, and 1.48% in the SA.

Introduction

The pure form of waterjet or when coupled with abrasives can machine materials that are tough to cut, such as brass, nickel-chromium alloy, and titanium. Unlike cutting procedures involving plasma or laser, abrasive waterjet cutting (AWJC) is distinguished by the absence of microcracking and thermal impacts on the cut surface (Wang et al., 2001). To conduct the desired activity, the principle involves converting the available pressure energy of water into kinetic energy by passing it through a small hole (orifice). Abrasive performance was discovered to be significant while taking cuts, and proper abrasive recharging improved the penetration depth of waterjets at a lower cost. In addition, a good surface finish was observed when AWJC of the metal alloy was compared to AWJC of pure metal as a parent (Shipway PH, Fowler G, et al 2004). Furthermore, cutting factors such as AWJ, CS, AFR, JA, and SOD was discovered to play a vital influence in defining the quality features of the cut surface. For off-line quality control, the research of parameters and their impacts on quality characteristics was critical, and an appropriate combination of parameters was required to achieve improved cut surface characteristics. Colemanite powder was a better alternative to garnet for producing surfaces with improved traits. SZ characteristics (zone length and SA) directly impact surface texture; hence, lowering the SZ and its angle was critical for producing a superior cut surface. It is possible to think of the AWJC technique as a multiple-input procedure that necessitates simultaneous optimization of several answers. ANN, RSM, GA, PCA, fuzziness-based approaches, and GRA are a few of the many methods that have been used to determine the optimal set of parameters in various production

processes. The kerf width and surface texture in AWJC were studied using multiple regression models, and SOD was found to impact the responses substantially. In a separate case, a similar regression analysis technique was applied, and the use of the Statistical Package for Social Science (SPSS) program was well achieved. However, the ability of the response surface approach in unstable regions of experimental trials was questioned, and the genetic algorithm's parameter setting was complicated. GRA, or a combination of grey theory and desirability analysis, helps determine the best parameters for desired surface features. PCA is an eigenvalue-based multivariate data analysis that can outperform Fourier transformations and factor analysis by considering the effects of variation in the data. PCA has been effectively used in various production contexts, either in its original form or hybrid versions, following adequate integration with known processes. A survey of the available literature revealed that little has been known about the properties of the SZ and that rare has been done to research the S_{ZN} in ZE41 is a magnesium alloy AWJC. Even though PCA and the theory of grey incidence have been used in numerous sectors, there is a lack of literature on an integrated approach of PGI, which combines the benefits of both methods to achieve optimal conditions. As a result, a parameter design attempt has been undertaken in AWJC using the PGI method to reduce S_R , S_{ZN} , and S_A . In the manufacturing sector, the abrasive water jet (AWJ) has been widely used to machine variety of materials, including both metals and non-metals. The decision to use the AWJ machining method was made because it does not generate heat in the area of cutting, but rather machining metal alloys produces less heat, and it is possible to cut any type of material metals, non-metals,

composites, and ceramics; a larger percentage generation of a higher MRR compared to the Wire EDM technique superior rather than laser cutting, surface integrity; thicker cuts components between 250 mm (depending on the material) and Not Standing with thermal distortion, materials can be worked, and complicated shapes can be cut; a minimum cutting force exists on the work materials. In AWJ machining, the material is removed by an erosion process in which hard abrasive particles are suspended in a high-velocity water jet stream. This technique accelerates the abrasive particles' impact on the target material and increases their kinetic energy. The injection type AWJ machining process' core design. High compression water becomes high velocity after flowing through the aperture and focusing nozzle and accelerating by several hundred metres per second. As a result, abrasive particles in the mixing chamber and nozzle get high velocity jet energy. Only garnet-type abrasives are used in more than 80% of industries. Typically, focusing nozzles are made of incredibly strong materials like sapphire, diamond, etc. the debris and fast-moving water jet entering the water filled cutting area during the machining Various researchers have worked to develop good-quality machining characteristics in laminated composites, according to an examination of the literature. Due of its cutting-edge properties, hybrid laminated composites are used to make bridges, machine tool frames, prefabricated walkways, and platforms, among other things. However, there is no study on the AWJM of laminated hybrid composite materials employing nanoparticles as filler material. The current work investigates the impact of cutting settings on the average surface roughness (Ra) and kerf taper (Kt) of hybrid (Carbon, S-Glass, and SiC nanoparticles) laminated composites. These variables include traverse

speed, water compression, abrasive mass flow rate, and stand-off distance (SOD). Multi-objective optimization was evaluated using the tested set of cutting parameters. The most common choice for machining materials has been 1 AWJ. Due to the primary advantages of this method, such as a smaller heat affected zone, reduced cutting forces, and no changes in material characteristics, almost all types of metals and their alloys are treated using the AWJ machining technology. With this method, materials with thicknesses ranging from 2 mm to 100 mm were sliced. More than 100 mm of thickness might also be cut using it. The lowest surface roughness obtained by AWJ polishing operations was 0.016 m.

1.1. EROSION PROCESS

The term "erosion" refers to the sort of wear that results from the constant impact of abrasive particles in a liquid medium moving at a high speed and the occurrence of erosion. In the process of removing material for AWJ machining, the effect of the abrasive particles is fundamental. According to tradition, the four sub processes of cutting, fatigue, melting, and brittle fracture are used in combination by to remove material from the workpiece surface using abrasive particles (Shipway PH et al 2002). Microcutting can cause erosive wear and other problems including cutting and deformation/ploughing deformation. mechanisms, material removal occurs in AWJ primarily in two ways The many types of machined characteristics of the AWJ cut surface. 2. Cutting distortion occurs through angular, sharp-edged particles, whereas spherical abrasive particles experience considerable ploughing deformation . A combination of cutting wear and deformation wear mechanisms cause ductile erosion. The target material is typically impinged with the narrow angle of attack of the abrasive particles in the cutting wear zone, creating a smooth cutting zone . Deformation wear, in contrast, occurs at high angles of attack and results in a rough surface with striations due to the abrasive particles' acute angle of attack Material removal during the brittle erosion process takes place through frictional compressions brought on by the collision of abrasive particles promote crack propagation and chipping. The target materials' material removal mechanism is influenced by jet impact angles. The extremely effective ductile shearing action caused by the oblique jet impact angle in the target materials limits fracture traces and partial chip on the machined surface, removal. Three zones have been created on the AWJ surface. The

initial damage region is provided at the top kerf wall cut surface by the expansion of the jet prior to impingement and the variation in jet energy with radial distance. The abrasive impingement angle in this area is far more than what is required for the remaining cutting depth. Under the first damage region, the cutting Both the cutting region, which is recognised for being rough, and the smooth region coexist. They can be identified by waviness profiles. The machined surface imposes the abrasive particle size in the area of the smooth cutting areas. In contrast, the rough cutting region surface characteristics are controlled by cutting settings that impact jet kinetic energy

1.2. MAJOR INFLUENCE OF ABRASIVE WATER JET MACHINING

(1) Water jet compression is a crucial procedure. parameters in AWJM. The kinetic energy of the AWJ is dependent on water's compression. When no material is removed, compression is lower than the threshold compression range. Similar to this, the stated limit for effective cutting is represented by a compression that is equivalent to the critical compression range. If the machining process is continued past this point, it loses its effectiveness. The penetration depth and the rate of material removal are directly inversely correlated with the water jet compression. It affects how abrasive and water-containing particles are distributed in the jet. Map, bar, or PSI are commonly used as indicators.

(2) Traverse speed: It establishes the standard within the sliced surfaces that the AWJ process produces. The selection of the exposure time has a significant influence on traversal rate m during the AWJ machining process.

By allowing more abrasive particles to slam against the target material's surface, a lower traverse rate improves surface quality. It also affects the process's cutting pace. mm^3/min is used to denote the traverse rate.

(3) Abrasives: The AWJ machining technique employs a variety of synthetic (silicon carbide, aluminum oxide) and natural (garnet) abrasives. Typical garnet abrasive form for use in the milling process, the size, shape, and hardness of the abrasive particles have a big impact on how well the AWJ cuts. The abrasives that should be utilized should be harder than the work material is. The particle disintegration rises as abrasive particle size increases. When the maximum size of the abrasive particles increases, the velocity of material removal and depth of penetration both decline, There is a universal indication of the abrasive size range.

(4) Abrasive mass flow rate: The AWJ material removal rate is influenced by compression of the water jet and flow rate of the abrasive. Higher cutting performance and improved surface finish are produced by an ideal supply of abrasives. The focusing nozzle's diameter, which is employed in the AWJ machining process, determines the abrasive flow rate. For the abrasive mass flow rate to be effectively accelerated, the jet momentum must be transformed. Kg/min is a common unit of measurement for abrasive mass flow rates.

(5) Stand-off distance is defined as the space between the nozzle and the substance it is meant to deliver. The kerf profile produced by the AWJ is frequently maintained by an optimal amount of distance in mm because to the considerable impact of SOD. The difference in kerf profile is shown in Fig. 2.

(6) Jet impingement angle: The cutting head tilting is connected to this angle. It is described as the angle between the target material surface and the AWJ's original flow direction. Any modification to the jet impingement angle will eventually result in a modification to the jet attack angle on the target material, which will impact the mode of erosion. The effectiveness of AWJ cutting is significantly impacted by the usage of the changeover jet impingement angle without incurring any additional costs. In the machining process, there are two basic types of jet impingement angles that are utilised: forward and backward directions. The benefits include the ability to machine very soft and fragile materials as well as reduced kerf taper production, striation formation, and contamination

7) work material: In the AWJ machining process, the work material is often desired in any size and shape. Hard materials including magnesium alloys, titanium alloy, Ceramics, stainless steels, composites, tungsten carbide, etc.. are used in the AWJ process. Abrasive contamination and striation generation are the two main phenomena observed in the work material following the machining process. The soft materials' abrasive contamination is higher with the structural applications since the work materials are harder. The cut surface of a hard substance, as opposed to a soft material, exhibits substantial striation production. This occurs as the cutting depth is increased, the abrasive attack angle increases and the kinetic energy of the abrasive particles decreases. Machining the hardened material at a lower cutting zone considerably reduces this cutting energy

8) Process parameters

1. Previous researchers have attempted to improve the AWJ's cutting performance using a variety of strategies, including the recycling of abrasives, changing the jet impingement angle, modifying the size and shape of the abrasive mesh, and nozzle oscillation technique, among others. These methods were created without incurring any additional costs and are efficient for AWJ machining any work material. A number of studies have often used and optimised the process parameters traversal rate, water jet compression, stand-off distance, abrasive mesh size, and abrasive mass flow rate. Further study when the nozzle and orifice sizes are changed, jet impingement It is necessary to use an angle, abrasive size, and abrasive mixture (mixing different types of abrasives). Oblique jet impingement angles are recommended for machining, according to recent study. materials that have a deep penetration
2. A majority of the researches have used a garnet abrasive mesh size # of 80 as a result of the higher cutting performance, prevention of clogging effect in nozzle and maintenance of surface quality. A large taper was found in garnet compared to that of Al_2O_3 and SiC abrasives. However, a smaller mixing tube wear and better machined surface
3. The combined impact of various jet impingement angles and abrasive mesh sizes, which have not been studied by researchers, is illustrated in the available literature. The impact of the jet impingement angle on materials with a narrow range, such as alumina ceramics, aluminium alloy, and die steel, has also received little experimental attention.

1.3. LIMITATIONS OF ABRASIVE WATER JET MACHINING

Even though the AWJ machining technique is well-known, it has several drawbacks. Short energy transfer efficiency from the nozzle to the work piece, abrasive contamination, taper and striation creation, rough quality surfaces, and a low depth of penetration all contribute to low material removal rates, among others, are some of these. The application of this method in the industries has been severely constrained as a result of these restrictions. are few of the consequences on the work materials of the AWJ machining process . Further, It has been thoroughly covered in the parts that follow.

1.4 APPLICATIONS OF ABRASIVE WATER JET MACHINING

medical Due to its inherent advantages, including Water jet technique is used for a variety of medical components due to its lower heat and cutting force requirements as well as its total lack of any adverse effects on thin section materials. Researchers have made several attempts at various medicinal uses, including removing cancer-affected areas from the liver and bone, orthopedic implants, and human dentin. As demonstrated in Table 1, all medical applications were completed with a reduced water jet compression. A smaller blood loss without heat buildup in the human organs is frequently achieved by using a lower water jet compression with regulated process parameter settings. AWJ is preferable to pure water jet for processing medical implants because it improves the texture, hardness, and fatigue life of the components. In order to improve the integrity between both the machining process as well as the biomaterials, a small abrasive is essential. All types of biomaterialsbone, Ti alloys, stainless

steel, Zr-based alloys, and NiTi alloys are some examples. may be processed with higher surface quality with this tool [Jerman M et al 2015]. As a result of this technique, human organs and biomaterials are not subjected to heat or stress, which can be destructive. The alterations in bone's alkaline phosphatase during machining processes are likewise limited by this cold processing technique [Kim SK et al 2009]. Below, a few discussions were offered. (Papachristou et al) employed the water jet procedure . for the liver Hepatocytes surround the vascular and intrahepatic hepatic billiard. They claim that using a saline jet to remove the liver has proven to be simple to utilize and has minimized blood loss. Later, [Schwinger et al.] looked into the use of AWJ machining to cut cancer-affected bone. Lactose-monohydrate was employed as a biocompatible abrasive in the experimental investigation. They came to the conclusion that despite its heterogeneity, An abrasive water jet can be used to cut through cancer-affected bone. The accuracy of the abrasive water jet is sufficient for osteotomy. A water jet produces not as much heat as an oscillating saw while cutting bone. The ability of the bone to heal itself was noticeably improved after using the water jet cutting procedure. this finding is supported by an in vivo research. Using a water jet, [Une et al]. [41] looked into hepatic resection. Here, this device was utilised to make precise, compression-controlled cuts into the afflicted tissues. The research involved 24 people who had hepta cellular carcinoma. The water jet procedure' regulated settings made it possible to safely resect the liver, both healthy and damaged. As a casting operation for processing orthopaedic implants, [Arola and McCain et al] employed AWJ. They demonstrated that the AWJ peening procedure increased The superior

surface roughness created by compressive residual stress increased the fatigue life of the implants. The removal of carious diseased tissues from human dentin via AWJ drilling was studied by [Kohorst et al. 2010]. They chose since manipulating the laser treatment settings, alumina particles for the drilling procedures is a time-consuming procedure and generates heat while being employed. While heat generation in the water jet machining method might be reduced by utilising cold water and adding abrasive particles, the pure water jet technique is more appropriate for industrial applications.[Shakouri and Abbasi] used the AWJ machining technique to investigate the Bovine femur bone cutting ability and surface roughness. bone samples that have been chopped and sliced by the AWJ. Variations in traverse speed, water jet compression, and abrasive kinds (sugar, garnet, and bone powder) were used in this investigation. According to the findings, using sugar as an abrasive during the cutting process increased the cutting quality of bone. They also suggested that the surface roughness of the bone cut surface is influenced by lower feed rate and greater water jet compression. The AWJ peening procedure was examined by [AROLA et al]. on orthopaedic metals like Ti6Al4 V alloy and SS 304. This method can prepare a variety of biomaterials for bioimplants. Research on the surface morphology and topography of the SS 304 AWJ milled surface pattern were investigated by [Yuvaraj et al]. Surface roughness (Sa) of the surface texture pattern ranged from 2 to 5 μ m. The authors also noticed that the milled surface had ridges and microscopic abrasive particles (black spot)

2.LITERATURE SURVEY

hybrid AWJM approaches Researchers claim that a number of hybrid techniques, including Cryogenic treatment of work materials, cryogenic aided AWJ, ice jet machining, oxy acetylene welding, laser setup, and ultrasonic setup are all examples of cryogenic treatment of work materials. shown in table 2 A hybrid process setup has been designed for the machining of delicate materials and improving cutting performance, despite the potential benefits of AWJ. This method' expertise has been used to a variety of applications, including nuclear and medical ones where the cut quality must be more exact without any heat-affected zones. The several hybrid methods are covered in depth below. Laser assisted water jet machining has been developed by [Kalyanasundaram et al] for scribing and cutting tough and brittle ceramic materials. The results demonstrated that laser-assisted water jet machining produced superior material separation and machined surface quality. By using AWJ cutting, [Hlavac et al.] examined the kerf taper cut in various steel grades with a thickness of 30 mm. This study focuses on the difficult challenge of precision cutting of hard steels with thickness more than 10 mm, which was resolved by AWJ. As a result of deformation brought on by the ductile work materials during the cutting process, they found that the production of ductility of the steel caused variations in taper cuts and curvatures in the entry of kerf wall cut surfaces. The The normal condition of the steel increased the variance between the entry and exit of the kerf width generated by AWJ at traverse speeds ranging from 5 to 50 mm/min.. A modified hybrid arrangement of the AWJ machining method is called ice jet machining. It generates parts that are free of contaminants. Cleaning, cutting, and deburring on diverse

materials were among the many operations done .Cryogenics was used in this method to replace insoluble abrasives with ice abrasives. LN2 has been primarily employed by researchers as a cryogenic for machining operations. For a variety of purposes, including the processing of delicate materials food meat hardwood billets, biomaterials, and biomedical applications revious researchers have conducted tests on ice jet machining. However, due to the ice jet's less effective machining process than the AWJ, this configuration is currently still in the experimental stage and has not yet been commercialised. This outcome is shown from [GUPTA et al]Cryogenic jet cutting systems for cutting steel with a 10 mm thickness have been proposed by [Kim et al. 2010] with a reduction in secondary wastes and particle pollution produced by the current AWJ method. Finite element and smoothed particle hydrodynamic techniques were used to conduct this investigation. The findings show that cryogenic cutting technique offers a variety of advantages, including changes in the target material's failure mode as a result of the low temperature produced by utilising cryogenic liquids. In order to conduct real-time experiments, design variables and operational conditions were established. The development of the cryogenic cutting process' flow line. Cryogenic ice jet cutting equipment was created by [Bach et al. 2017] for the purpose of cutting and cleaning aluminium alloy (AlMgSi1) with a 3 mm thickness. Instead of using traditional abrasives, ice particles were employed as an abrasive in this investigation. A custom-made two-axis Ice abrasive water jet cutting system's temperature monitoring was later the subject of research by [Jerman et al. 2015]. Ice abrasives were used in this investigation to substitute mineral abrasives. The foam used for the

experiments had a thickness of 20 mm. The results showed that the injected ice abrasive performed better in cold water. Abrasive jet machining and ice jet cutting are both related processes. Soft materials are selectively removed by it. [Tsunemoto et al.2019]carried out these investigations. Fine ice particles created at cryogenic temperatures below 150 °C were employed in this cutting procedure. The nozzle's ice jet stream's focal point made it possible to drill small holes. AWJ cutting steel cryogenic treatment, namely 1.4307, 1.4404, and 1.4845, has been studied by [Uhlar et al.2016]. They examined the cutting of non-corroding steel samples with cut surfaces that were 30 mm thick and treated with LN2. . For this investigation, A jet impingement angle of 90° was used, as well as a garnet abrasive mesh size of #80.. Declination angle and surface roughness were taken into consideration in this investigation as responses. [Lv et al 2007]. developed the ultrasonic-aided AWJ machine configuration for machining and polishing activities. They claimed that their solution was more efficient than the AWJ procedure. A thermally improved AWJ machine configuration Patel and Tandon invented a method for processing Inconel 718, Ti-6Al-4V alloy, and mild steel. The oxyacetylene gas welding setup of the AWJ machine helped create this hybrid method. Additionally, They developed a gelatinenabled abrasive water slurry jet arrangement for mild steel cutting in an AWJ machine. Cryogenic assistance system for the AWJ machine has been created by Yuvaraj and Kumar for the machining of aluminium alloy and die steel. Through the employment of the cryogenic machining technology and the favourable adjustment of the erosion process in the cutting zone, they have documented improvements in cutting performance and surface integrity features. Through the application of several

characterisation techniques, the results were verified. [Haghighi N et al 2019] Investigated The use of metal masks in ductile and brittle materials to reduce geometrical features by approximately 150 mm was also investigated. According to [Liu et al. 2014], the AWJ machine tool's 5 axis articulated head attachment was used to produce 3D complicated shaped profiles. In a variety of procedures, this attachment is employed for the taper compensation. Additionally, it is more efficient for cutting turbine blades for use in jet engines. Microabrasive wipes

2.2 Major influence of awjm process parameters

Research on the effect of abrasive mesh sizes on AWJ cutting aluminium alloy was conducted by [Yuvaraj and Kumar et al 2009]. When oblique jet impingement angles were applied, they observed that the surface roughness of various cutting zones was reduced to an abrasive mesh size of 1200. It was observed that the abrasive mesh sizes #80 and #100 had an impact on the kerf shape and depth of penetration. Additionally, they observed that when using abrasive mesh size #80 and a jet impingement angle of 90°, greater particle disintegration occurs. The impact of the AWJ cutting settings on the penetration depth and Ra for stainless steel is reported by [Kulekei et al 2014] . an increase in water jet compression that results in deeper penetration. Additionally, he discovered that when the average particle size of the abrasives increased by 0.2 mm, the depth of penetration increased. While large size abrasive particles were used, a small number of abrasive particles impinged on the target material as the acceleration was reduced due to the increase in mass of the abrasive grains, resulting in variations in the depth of penetration. The impact of garnet and silicon carbide abrasives in the AWJ cutting of Al-SiCp MMCs has been researched by [Srinivas and Babu et al

2007] They noticed a relationship between the size of the SiC particles in the matrix material and the choice of abrasives (type of material and size). The outcome also showed that when cutting Al-SiCp MMCs, abrasive mesh size #80 delivers superior cutting performance regardless of the abrasive materials. The impact of abrasive size and shape on the AWJ cutting of concrete has been studied by [Karakurt et al. 2017]. For the AWJ cutting procedure, abrasive particles with sizes of coarse grain (3.6 mm), medium grain (1.5 mm), and fine grain (0.9 mm) were utilised. The study's findings indicated that while fine-grained abrasives created a greater cutting wear zone and wider kerf width in all of the concrete samples, coarse-grained abrasives had a more favourable influence on the depth of penetration and kerf width. Wider kerf breadth was a result of the water jet's increased velocity during the cutting process, which allowed the low-weight abrasive particles (fine grains) to spread between the nozzle and the work material. [Karakurt and et al 2019]. They employed several granite compositions for the AWJ cutting procedure. The outcome shown that the mass flow rate of the abrasive does not affect the taper angle for cutting different granites. In a study of the interaction between abrasive mesh size and other process factors in the cutting of granite with mesh sizes of #80 and #120, [Karakurt et al 2014]. They noticed that a greater depth of penetration was generated by garnet mesh size #80. Because there were more coarse particles present, the material could be sliced with more force using the #80 abrasive mesh size. All of the granites tested showed a reduction in cut depth when the abrasive mesh size was increased. The weight of the abrasive particles and their kinetic energy determine how cutting-edge they are. For cutting, the material, Using garnet abrasives with a single mesh

size, studies on AWJ cutting of AA6063-T6 have been conducted by [Kantha babu & Chetty et al 2019]. They took into consideration abrasive mesh sizes in the #52–#80 range. According to the findings, single mesh size abrasives outperformed multi mesh size abrasives in terms of cutting rate. Because of the irregularity of fragmented abrasive distribution in the jet, using single mesh size abrasives is notable for its surface roughness and deviates in kerf taper. However, in terms of penetration depth, the behaviour of abrasives with a single mesh size is comparable to those with several mesh sizes. Additionally, they came to the conclusion that the cutting behaviour of single mesh size and multi mesh size abrasives is similar.

2.3 Surface integrity study on awjm By adjusting the jet impingement angles, [Yuvaraj and Kumaret et al 2008] looked at surface topography and morphology investigations on D2 steel. The jet impingement angles used by the AWJ to mill die-cut surfaces of steel were 70° and 90°. Lower striations with an average trough width of 348 m were formed by a jet impingement angle of 70°, whereas severe striations with a trough width of 978 m were seen in the cut surface at a jet impingement angle of 90°. The water jet was deflected in the lower cutting zone because to the wavy distribution of abrasives caused by this impingement angle. Surface investigations on CoCrMo alloy were done by [Cashman et al.2016]. The AWJmachined CoCrMo alloy This denotes the presence of abrasive contamination on the top and bottom cut surfaces. The surface of the top cut reveals a heterogeneous sort of morphology. It attests to the elimination of material by microchipping and ploughing operations. Given that the densities of both materials were equivalent, analogous processes may potentially be identified in stainless steel. It was suggested that micro-

chipping was the main mechanism at the top cutting zone, where the angle of abrasive impingement is high. The black patches in the bottom cutting region represented abrasives embedded in the sliced surface. This occurred as a result of the interaction between the lower kerf wall and small-size fracture abrasives. Abrasives severely degraded in the top cutting zone, resulting in fragmented abrasives. Similar findings were obtained in an aluminium alloy cut surface study by [Yuvaraj and Kumar et al 2007]. The surface morphology and topography research on the AWJ milled surface pattern of SS 304 were investigated by Yuvaraj et al. [31]. Surface roughness (S_a) of the surface texture pattern ranged from 2 to 5 μ m. The authors also noticed that the milled surface had ridges and microscopic abrasive particles (black spots). The effect of material qualities on surface integrity as a result of the AWJ cutting of several work materials, such as Al 7075-T6, Molybdenum, Ti-6Al-4V, Monel 400, and AISI 304 stainless steel, has been highlighted by [Arola & Ramulu et al 2019]. They discovered that the AWJ cutting of metals occasionally caused subsurface deformation, which was brought on by the strain hardening of the metals and the jet impingement angles. By using scanning electron microscope pictures, [Kovacevic et al 2019] tackled the issue of the surface roughness in AWJ cuttings of AISI 304 stainless steel. As a result of the production of striations at the exit of the work material, the findings showed that the top cutting region was characterised by a smooth texture and the bottom cutting region by a rough texture. When using the oscillation cutting method, as shown by [Patel et al 2019], an increase in cut depth was followed by a reduction in the amount of abrasive particles embedded in the kerf wall cut surface by more than 50%. zone of the sliced surface.

However, the geometrical parameters did not significantly use oscillation cutting. With subsequent treatment of these surfaces, such as grinding, welding, and/or coating, the contaminated zone under normal cutting mode may produce major issues. The nozzle oscillation approach has been examined by [Chen et al.2020] for reducing the embedded abrasive in the mild steel AWJ machined surface. They noticed that the nozzle oscillation approach reduced particle embedment, and that reduced particle reinforcing steel in the workpiece surface had a favourable impact on the material's fatigue performance. However, it was discovered that the nozzle head oscillation approach had no effect on the penetration depth. The ultrasonic cleaning method was employed by [Boud et al.2015] to clean AWJ machined surfaces. Additionally, compared to WEDM, LBM, and milling processes, the Ti-6Al-4 V alloy surface produced by AWJ machining had a greater fatigue resistance (No. of cycles to failure - around 500,000). In AWJ cutting of cold work mould steel, 6061 aluminium alloy, high strength low alloy steel, and AISI 304 stainless steel, [Zhao & Guo et al 2017] studied cut surface characteristics. as a consequence of deflection, deformation, and area) caused by the use of sharp edge and angular cutting tools at lower cutting depth, whereas ploughed deflection (bottom cutting region) was created by the use of spherical morphology abrasives and small fragmented abrasives. Surface waviness is a worn zone caused by deformation. It occurs as a result of the AWJ's energy being lost at deeper cutting depths. By using various abrasive mesh sizes, [Fowler et al.2016] examined the abrasive impurity on the milled titanium surface. A circle surrounds the polluted area (particle embedment). The properties of the cut surface were significantly impacted by milling direction at slower

traversal speeds. The findings demonstrated that using various abrasive mesh sizes produced contamination in the milled surface that ranged from 5% to 40% and that the contamination had a noticeable impact on the component's surface integrity because of the high velocity of the abrasive material. When milling titanium alloy using an AWJ, [Shipway et al. 2015] varied the jet impingement angles and abrasive mesh sizes. The results show that a 60° jet impingement angle produces a greater rate of material removal and a better surface finish than a conventional jet impingement angle, which results in a significant impact on the cut surface. According to [Uthayakumar et al. 2017], the water jet compression prevents craters from forming on the cut surface. With the use of an AWJ, [Akkurt A. et al 2017] reported drilling materials made of pure aluminium, brass 353, AISI 304 stainless steel, AISI 1030 steel, and D3 tool steel. Their analysis suggests that AISI 304 and D3 steel, both of which are challenging to machine, may be employed in production. With an increase in material thickness, the quality of the drilled surface decreases. The cutting effectiveness of the abrasive particles in the water jet decreased due to a drop in jet velocity when the focusing nozzle was removed. [Wanget al 2009] studied how the AWJ cutting performance affected the machining of polymer matrix composites. He discovered the ideal jet impingement angle for the surface quality, kerf profile, and penetration depth. The outcome indicated that while cutting polymer matrix composites, a jet impingement angle of 80° produced superior cutting results. Xu Z, [Dunleavey et al 2020] investigated the titanium alloy's AWJ cut-edge surface, which is where fractures first started. The treated surface has no additional faults save the striations. This outcome was attained as a result of the AWJ machined surface

developing increased compressive residual stress. Additionally, researchers claim that AWJ and laser cutting have less of an impact on surface hardening than the Wire EDM procedure. [Lenin Raj and Rajaduraj et al 2019] looked at AWJ machining's ability to repair holes in deep holes. This hole correction approach lessens the surface roughness and undesired hole geometry of the deep holes. Some research projects concentrate on inclined hole drilling with the AWJ method

3.AIM AND SCOPE OF THE WORK

The increased requirement for cutting-edge machining methods for numerous applications has made AWJ incredibly helpful for manufacturing engineers in resolving a wide range of challenges. The following themes provide several chances to academics and scientists who may use AWJ and its hybrid processes to develop answers for difficult jobs in various industries.

3.2 SCOPE OF THE WORK

1.Aerospace and defence industries: For external cooling applications, the manufacturing of tiny holes and channels in large temperature modules is crucial. The use of AWJ's tiny jet nozzle assembly makes it possible to drill holes with a diameter of 300 mm. The researchers have a lot of room to study the jet profile, hole geometry, and surface details thanks to this technique. Additionally, it would be advised to use the same machine tool for peening and blisking aerospace components such as turbine blades, aircraft frames, and other high temps components.

2. Automobiles, buildings, and railroads: The fast advancement of building and vehicle materials has led to the recommendation of a special machining method for processing a variety of highstrength structural elements.

3. Medical: As the number of bio implants in the human body has increased, AWJ has become an essential component of the different bio implants for processing and shaping bio materials without cracking, heating up, or changing the material's characteristics. Additionally, this procedure

stops the heat necrosis of the bone's machined area. For orthopaedic surgical procedures and the care of bio implants, the AWJ technique is advised to use bio/soluble abrasives (salt, sugar, and bone powder). The new advancements in bio/soluble abrasives for the medical domains will be established by this

4. Tools for cutting: An AWJ machine tool with a small jet nozzle arrangement opens up new possibilities in the creation of various texture patterns, such as micro dimples and micro grooves, to improve the tribological qualities of cutting tools.

5. Process development: Additional research is recommended in cryogenic, laser, ultrasonic, and slurry assisted Injection type and suspension type AWJ machining processes to address the machine tool's many inherent issues, including surface contamination, rough surfaces, poor jet penetration rates, taper formation, and striation. This could facilitate the commercialization of hybrid operations' introduction into the world market.

6. Machining process:

1. There is little current literature on AWJ drilling, milling, deep hole drilling, polishing, and peening operations, and research organisations' accomplishments in this area continue to be minuscule. For the study of AWJ capabilities in the aforementioned operations on hard materials, further findings are needed.

2. AWJ turning procedures have been discussed in several published works. However, the surface quality of the turned components is not satisfactorily improved by this method of turning. For the purpose of producing a superior surface, turning activities would need to be the subject of significant research.

3. Medical applications: Researchers have discovered the potential use of AWJ in combination with alternative abrasives in therapeutic diagnostics including cutting liver sections and cutting cancer-affected regions in bones. On the other hand, there aren't many reports on medical uses. Future biomaterial processing for the medical professions would use the AWJ process as the principal machine tool. According to earlier studies, AWJ is capable of bringing about positive changes in the medical sphere ZE41 is a magnesium casting alloy containing zirconium, rare earths and zinc. This alloy is well-suited for high integrity castings that are operated at ambient temperatures or up to 149°C (300°F). It is easily weldable and pressure-tight.

Materials and Methodology

4.1 MATERIALS REQUIRED

ZE41 is a magnesium casting alloy containing zirconium, rare earths and zinc. This alloy is well-suited for high integrity castings that are operated at ambient temperatures or up to 149°C (300°F). It is easily weldable and pressure-tight. [Magnesium alloy](#) ZE41, used extensively in the aerospace industry, possesses excellent mechanical properties albeit poor [corrosion resistance](#). This paper investigates the mechanism of corrosion and the interaction between the grain boundary [intermetallic phases](#), the Zr-rich regions within the grains and the bulk Mg-rich matrix. The results of optical and scanning electron microscopy (SEM) together with energy-dispersive X-ray (EDX) and atomic force microscopy (AFM) potential map measurements have shown the importance of the microstructure in the initiation and propagation of corrosion in an aqueous environment, indicating that the Zr-rich regions play a distinct role in the early stages of corrosion in this alloy. ZE41, which is a Mg–Zn–RE–Zr based alloy, is used for components such as aircraft gearbox and generator housings, particularly in military helicopters [34], which are exposed to corrosive environments during service. The relationship between the microstructure and the corrosion behaviour of ZE41 therefore needs to be better established and is the focus of this paper.

The microstructure of ZE41 consists of the α -Mg matrix containing finely distributed particles [35], thought to be β -phase particles, and the T-phase ($\text{Mg}_7\text{Zn}_3\text{RE}$) distributed eutectically at the grain boundaries. The β -phase is difficult to detect. Wei et al. could not detect it in a model Mg–4Zn–1.5RE

alloy [36]. However, unidentified precipitates with sizes in the range of 3–300 nm, possibly β -phase, have been reported for a commercial composition of ZE41 [35]. Zhao et al. have studied the effects of microstructure on the corrosion of a model Mg–Zn–RE alloy [37]. They conclude that the grain boundary T-phase acts as a cathode to the neighbouring α -Mg matrix, resulting in a galvanic couple between the grain boundary phase and the Mg-rich matrix, as the dominant the corrosion mechanism [37]. This is a common feature of magnesium alloys [38]. However, the alloy investigated by Zhao et al. did not contain Zr and was a model alloy differing in composition (and microstructure) to commercial ZE41 alloys. Given this difference, it should not be assumed that the corrosion properties of the commercial alloy will mimic those of the idealised system.

Methodology

The experimentations were run on a dual amplifier and pump system-equipped three-axis abrasive waterjet cutting machine (model: S3015, profile SL-V 50 HP). The device operated a 0.28 mm diameter (sapphire) injection nozzle that can discharge the water jet at a maximum pressure of 3600 bar using a PLC-based system. During several cutting trials, garnet (80 mesh) was utilized as the abrasive, and the nozzle was held at a right angle to the cut surface. Figure 1 depicts the machine setup and machined samples. The AWJC parameter levels were chosen based on available literature and pilot experiences. Taguchi's L OA was employed for experimentation, with each parameter being varied at five levels. The variable cutting levels utilized in the tests are displayed in Table 1. After the numerous trial cuts, the S_{ZN} , S_A , and S_R were observed as representatives of surface texture. Lower S_{ZN} , S_A , and S_R values might improve the surface texture. Therefore, all of the observed responses were treated as the smaller-the-better characteristics. The cutting surface has two distinct zones: one has no striations indicating cutting wear and the other has striations indicating deformation wear to the bottom¹⁵. For measuring angles, it features a predetermined square on the screen with a built-in transparent protractor. The length of the bottom section chosen as the S_{ZN} was measured using an optical microscope and an optical micrometer, and the S_A was calculated using the programmed MB Ruler 4.0'. The S_R was determined using a surf-coder roughness tester with a contact stylus (Model: SE3500). The roughness profile's arithmetic mean deviation (R_a) was measured for a sampling length of 4 mm and measured at a speed of 0.1 mm/s. Figure 1 shows the photographs of a few cut samples displaying

striation and line sketch of S_{ZN} . Figure 2 shows the EDAX image of ZE41 Magnesium alloy.

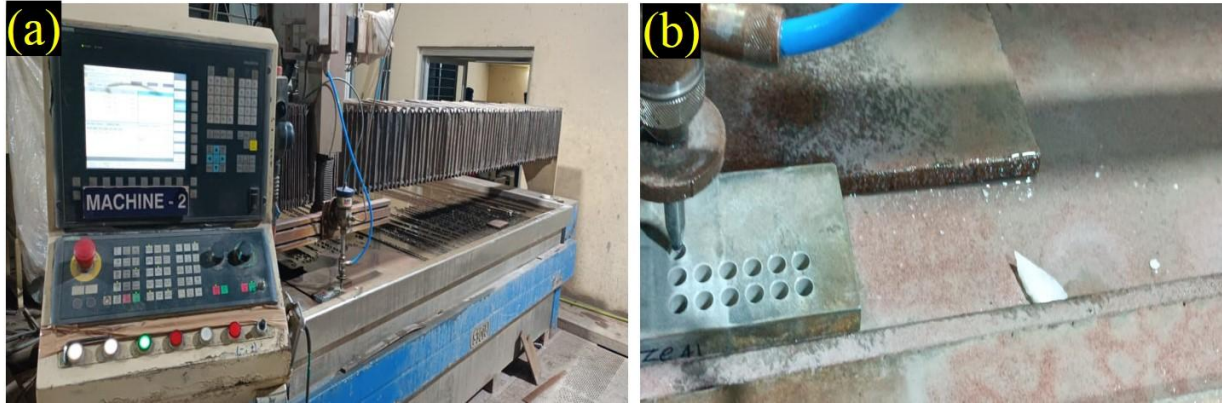


Figure 1. (a) Photographs of AWJM setup (b) machined samples

Table 1. Machining variables and levels

Input parameters / Levels	1	2	3	4	5
Abrasive water jet pressure, AWJP (MPa)	150	200	250	300	350
Stand-off distance, SOD (mm)	0.5	1	1.5	2	2.5
Table speed, TS (mm/min)	50	65	80	95	110
Abrasive flow rate, AFR (g/min)	200	250	300	350	400

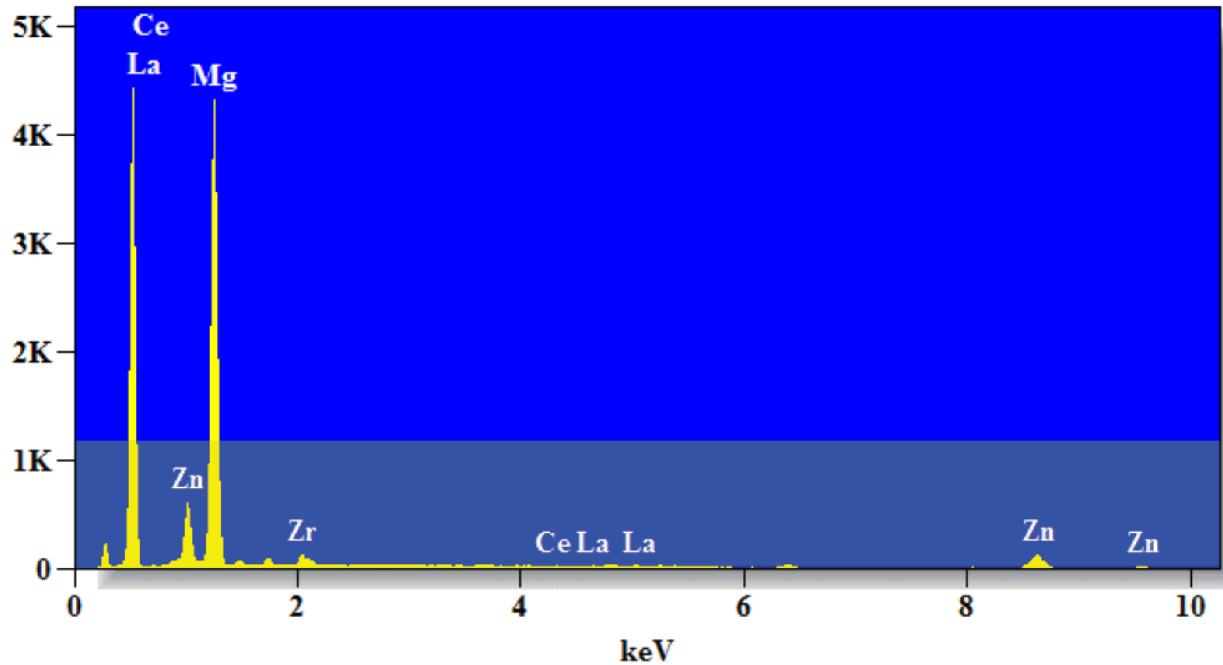


Figure 2.EDAX image of ZE41 Magnesium alloy **Table 2.** Parameter Levels and Response

S.N o	Run order	Input Parameters				Response		
		AWJP	SOD	TS	AFR	S _R	S _{ZN}	S _A
		MPa	mm	mm/ min	kg/mi n	μm	mm	degree
1	26	350	0.5	50	400	3.11	4.928	7.575
2	15	350	0.5	110	400	2.68	4.899	8.598
3	6	350	2.5	50	400	4.13	5.057	7.974
4	22	350	0.5	50	200	3.50	5.057	8.065
5	23	350	2.5	110	400	3.52	5.232	8.151
6	17	350	2.5	50	200	3.86	5.363	6.726
7	3	350	0.5	110	200	4.18	5.340	8.231
8	7	300	1.5	80	300	3.90	4.159	8.421
9	1	350	2.5	110	200	3.96	5.716	6.786
10	13	150	0.5	50	400	4.09	4.587	9.151
11	10	250	1.5	80	350	4.12	5.780	9.335
12	27	250	1.5	65	300	4.14	6.033	8.579
13	16	250	1	80	300	4.16	5.715	9.845
14	24	250	1.5	80	300	3.88	6.432	9.879
15	19	250	1.5	80	300	4.23	5.879	6.758
16	9	250	1.5	80	300	4.25	6.432	9.785
17	25	250	1.5	95	300	3.59	5.489	7.186
18	14	250	2	80	300	4.34	6.472	11.433

Results and discussion

All the material substrates were subjected to the metallurgical surface treatment of carbonitriding using the combination of inputs prescribed by the L_{18} orthogonal array. The responses obtained were subjected to further analysis. The effects of individual parameters to the response was displayed in Figure 3, 4, 5 and 6. The higher level of AWJP gives lower range of SR, SZ and SA as shown in Figure 3. The moderate level of SOD gives lower range of SR, SZ and SA as shown in Figure 4. The lower level of TS gives lower range of SR, SZ and SA as shown in Figure 5. The higher level of AMFR gives lower range of SR, SZ and SA as shown in Figure 6.

5.1 Effects of variables on the response

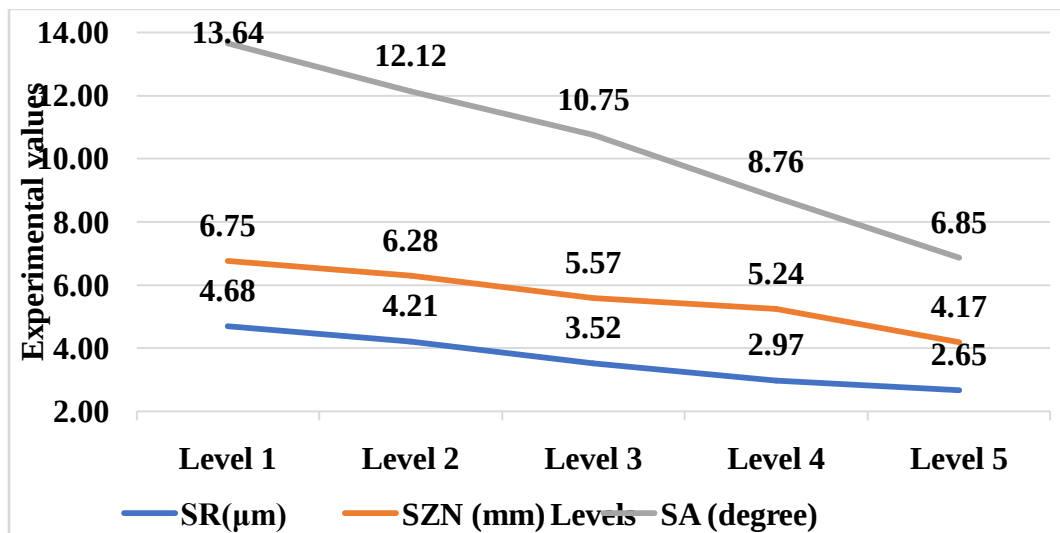


Figure 3. Effects of AWJP on S_R , S_{ZN} and S_A

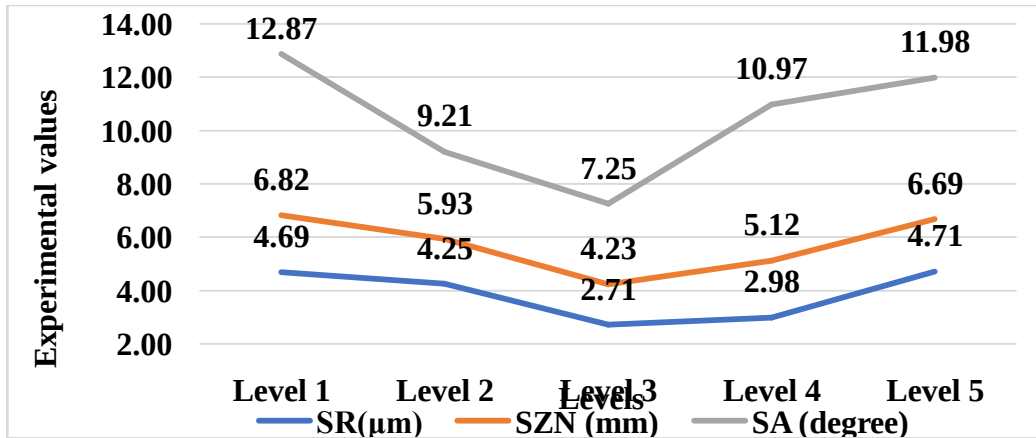


Figure 4. Effects of SOD on S_R , S_{ZN} and S_A

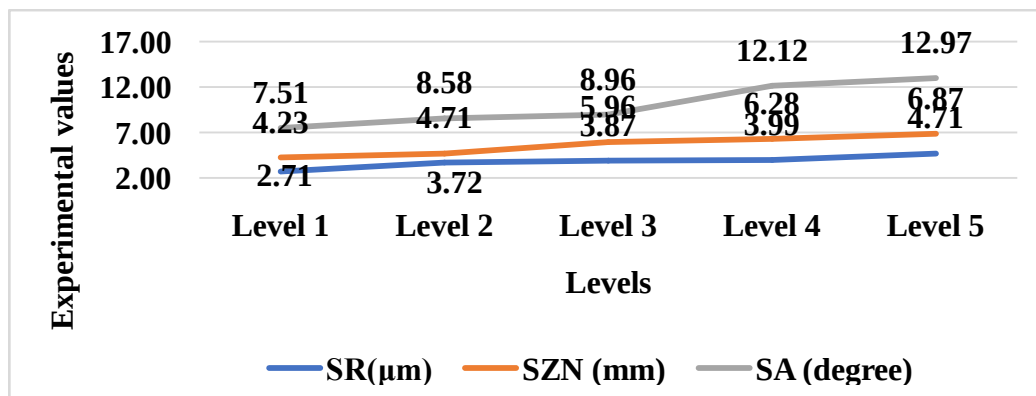


Figure 5. Effects of TS on S_R , S_{ZN} and S_A

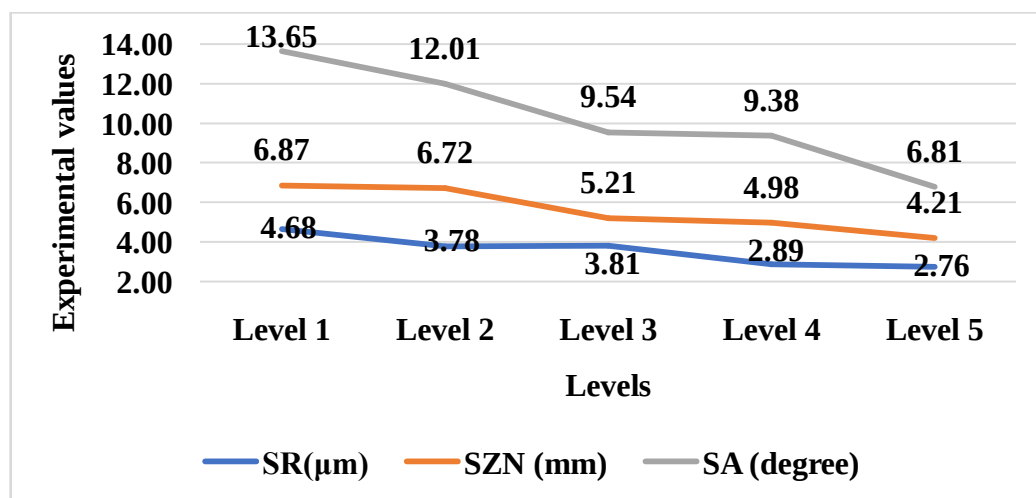


Figure 6. Effects of MFR on S_R , S_{ZN} and S_A

5.2 Principal Components based grey incidence (PGI)

An efficient method for offline quality control is the simultaneous optimization of a number of responses. Simultaneous optimization of many responses in a manufacturing process is highly challenging and necessitates additional experimental trials and compound analysis. In an innovative principle component-based grey incidence (PGI) methodology, an attempt has been made to combine the advantages of Eigenvector analysis and grey incidence theory. Two stages are used to present the various PGI technique steps.

5.3 Pre-processing and normalization of S/N ratio

The necessary equations (Eqs. (1-2)) were used to compute the requisite signal (process average) to noise (standard deviation), quantified as the S/N ratio, for different quality parameters. The S/N ratio is the reciprocal coefficient of variation, which reflects the relative dispersion of data, and is used as an initial indicator. With intended values of 1 (maximum) and 0 (lowest), respectively, the hardness and diffusion depth were considered as "larger-the-better" quality characteristics, while wear loss was "smaller-the-better" in nature. By improving the comparability of process variables, data alignment towards a normal distribution makes the analysis more understandable. Via a scaling method called linear normalisation, the experimental data was changed from 0 to 1. The first stage of data pre-processing is finished using Eq. (3), and the pre-processed data is shown in Table 3.

Table 3. Pre-processed response data

Trial	S/N ratio			Normalized S/N ratio		
	S_R	S_{ZN}	S_A	S_R	S_{ZN}	S_A
1	-6.848	-10.842	-14.577	0.738	0.623	0.834
2	-5.561	-10.792	-15.678	1.000	0.623	0.657
3	-9.304	-11.068	-15.024	0.238	0.557	0.762
4	-7.868	-11.068	-15.122	0.530	0.509	0.746
5	-7.918	-11.363	-15.214	0.520	0.518	0.731
6	-8.712	-11.577	-13.545	0.359	1.000	1.000
7	-9.409	-11.540	-15.299	0.217	0.386	0.718
8	-8.803	-9.369	-15.497	0.340	0.811	0.686
9	-8.938	-12.131	-13.622	0.312	0.365	0.988
10	-9.225	-10.220	-16.219	0.254	0.282	0.570
11	-9.289	-12.229	-16.392	0.241	0.387	0.542
12	-9.332	-12.601	-15.658	0.232	0.158	0.660
13	-9.375	-12.130	-16.854	0.224	0.332	0.467
14	-8.764	-13.156	-16.884	0.348	0.158	0.463
15	-9.523	-12.376	-13.586	0.194	0.464	0.993
16	-9.564	-13.156	-16.801	0.185	0.146	0.476
17	-8.089	-11.780	-14.119	0.485	0.742	0.908
18	-9.729	-13.211	-18.153	0.151	0.140	0.258

Table 4. PCA and Normalised PCA

Trial	Principal components			Normalized principal components		
	S_R	S_{ZN}	S_A	S_R	S_{ZN}	S_A
1	0.738	0.623	0.834	104.856	0.777	0.977
2	1.000	0.623	0.657	124.637	0.494	1.129
3	0.238	0.557	0.762	61.646	0.882	0.359
4	0.530	0.509	0.746	80.260	0.729	0.771
5	0.520	0.518	0.731	80.099	0.722	0.733
6	0.359	1.000	1.000	105.094	1.244	0.191
7	0.217	0.386	0.718	46.870	0.780	0.503
8	0.340	0.811	0.686	88.846	0.864	0.091
9	0.312	0.365	0.988	52.780	1.003	0.921
10	0.254	0.282	0.570	41.575	0.576	0.534
11	0.241	0.387	0.542	48.576	0.595	0.358
12	0.232	0.158	0.660	30.520	0.627	0.752
13	0.224	0.332	0.467	42.982	0.506	0.330
14	0.348	0.158	0.463	39.134	0.383	0.700
15	0.194	0.464	0.993	51.388	1.096	0.651
16	0.185	0.146	0.476	25.806	0.458	0.524
17	0.485	0.742	0.908	94.870	1.000	0.582
18	0.151	0.140	0.258	22.544	0.251	0.272

5.4 Grey incidence coefficient and desired performance index (DPI)

To better depict the variance-covariance structure, each response's linear combination was used. The normalised values of the S/N ratio of replies were used to create a correlation coefficient array. Eqs. (5, 6) were used to determine eigenvalues, eigenvectors, and principal components, and the uncorrelated principal components were oriented downwards by taking variance into account. This stage successfully changes correlated variables (observations) into uncorrelated variables (principal components), previously considered dependent components, obviating the need for an independent component analysis shown in Table 4. The three principal components have eigenvalues of 0.767, 0.873, and 1.251, respectively, with proportions of explained variation (PEV) of 0.2654, 0.3021, and 0.4325. The obtained values of normalised principal components and DPI values are shown in Table 5.

Table 5. GIC and DPI values

S. No	Grey Incidence Coefficient (GIC)			DPI Grade
	S_R	S_{ZN}	S_A	
1.	0.457	0.489	0.943	0.630
2.	0.496	0.428	1.000	0.641
3.	0.392	0.516	0.765	0.558
4.	0.418	0.477	0.875	0.590
5.	0.417	0.476	0.863	0.585
6.	0.458	0.639	0.728	0.608
7.	0.373	0.490	0.800	0.554
8.	0.431	0.511	0.707	0.550
9.	0.380	0.552	0.923	0.618
10.	0.367	0.444	0.808	0.540
11.	0.375	0.448	0.765	0.529
12.	0.355	0.455	0.869	0.560
13.	0.369	0.430	0.758	0.519
14.	0.364	0.408	0.854	0.542
15.	0.379	0.582	0.840	0.600
16.	0.350	0.421	0.806	0.526
17.	0.440	0.551	0.821	0.604
18.	0.347	0.386	0.745	0.493

The output responses with varying quality characteristics and the normalised principal components were employed to create a single reference object (DPI). The grey incidence coefficients serve as the foundation for determining DPI values. As a result, PGI's integrated technique efficiently simplifies a multi-response problem to optimise a single criterion, allowing for simultaneous optimization. The impacts of carbonitriding inputs on quality attributes were investigated using DPI values. Figure 7 shows the DPI levels for various experimental trials presented on a graph. These single representative values aid in presenting an overall view of the effects of defined parameter combinations on the examined responses. Their contribution manifests in transforming a multi-response optimization issue into a single-response optimization problem. Regardless of the nature of various responses, which may demand maximisation, minimization, or a user-defined target value, a higher DPI value determines superior surface qualities¹⁸. The DPI value for trial number 26 was found to be the highest, indicating that the experimental settings were close to being near-optimal. Table 6 displays the ANOVA analysis indicating that the most dominant factor in determining the DPI is abrasive water jet pressure, which contributes 44.31%, followed by stand-off distance, which contributes 7.95%, and mass flow rate at 4.48%, and table speed at 3.83%. Figure 8 shows the contribution between the parameters which depicts AWJP significantly contributes to striation zone (S_{ZN}), striation angle (S_A) and Surface roughness (S_R).

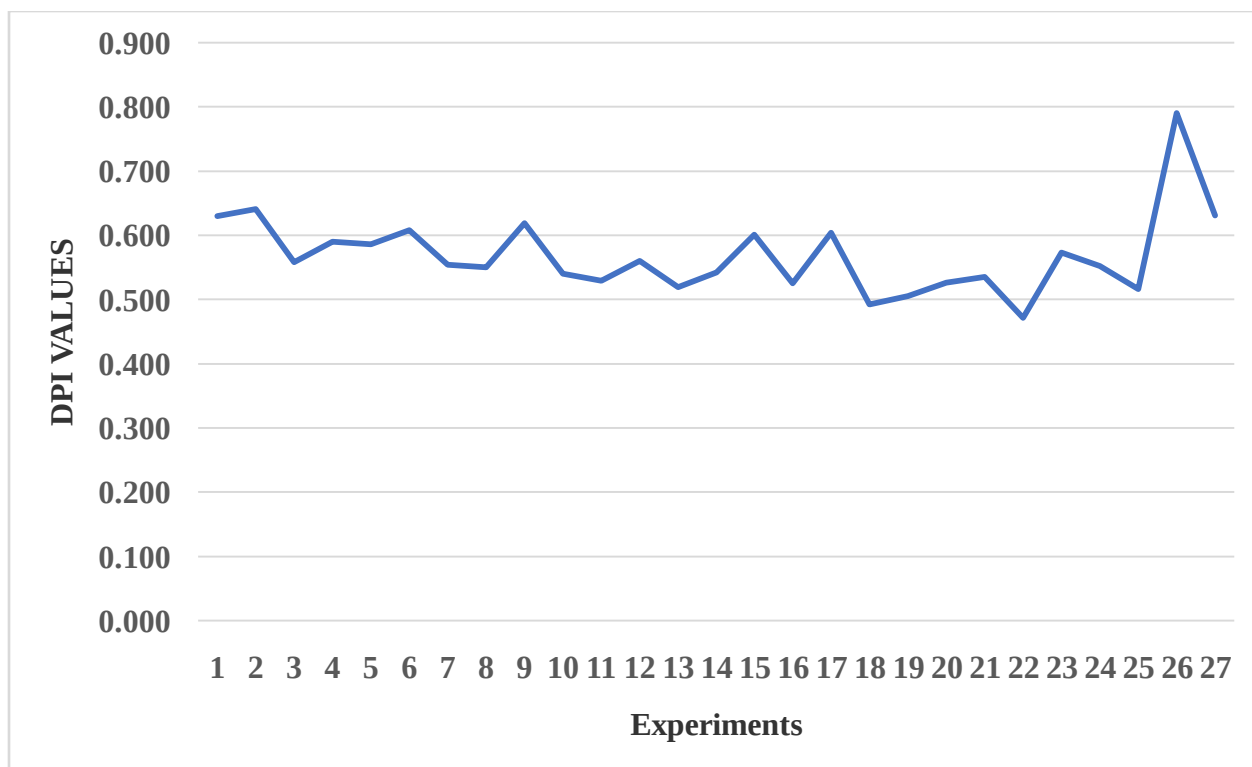


Fig. 7 DPI values for various experiments.

Table 6. ANOVA Analysis of DPI values

Factor	SS	DoF	MS	F	% Contribution
AWJP	0.1204	2	0.0602	25.2947	44.3112
SOD	0.0216	2	0.0108	4.5416	7.9560
TS	0.0104	2	0.0052	2.1891	3.8349
MFR	0.0122	2	0.0061	2.5587	4.4824
Error	0.1071	45	0.0024		39.4155
Total	0.27165	53			100

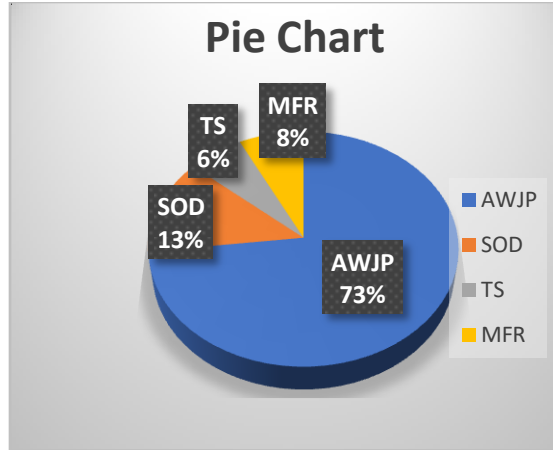


Figure 8. Pie Chart for Parameter contribution

5.5 Surface Topography Analysis.

The changes in input parameters impact the formation of distinct profiles and mechanisms of erosion, as shown in Figure 9. The machined surface of work material using AWJM is divided into two regions, such as top and bottom regions, based on its material removal mechanism¹⁹. The top region appeared as a smooth cut surface due to the cutting wear involved in material removal, whereas the bottom region appeared as a rough region with striation marks due to the deformation wear. The surface quality is mainly affected due to the uneven surface texture at the bottom region. The aqua jet at high abrasive pressure provided sufficient kinetic energy to shear the material at the bottom region²⁰. In contrast, the particle with lower energy formed the plastic deformation, producing the rough surface. Figure 9(a) depicts the smoother surface quality generated in the centre region of the ZE41 is a magnesium alloy machined surface with peck and scratch at a higher jet pressure AWJP (350 MPa), whereas Figure 9(b) depicts the rough surface with embedding and ploughing at a lower jet pressure (150 MPa) due to ductile erosion. As a result, the ductile metal contains many small embedded particles. Furthermore, increasing the jet pressure (AWJP)

increased the erosion of ZE41 is a magnesium alloy, creating a slight contour pattern on the surface²¹. The microscopic analysis is performed on FESEM images observed at the higher levels of each parameter, with the remaining parameters maintained at a medium level. The SEM images of parameters such as jet pressure (AWJP), table speed (TS), Stand-off distance (SOD), and mass flow rate (MFR) are shown in Figure 9 (c, d).

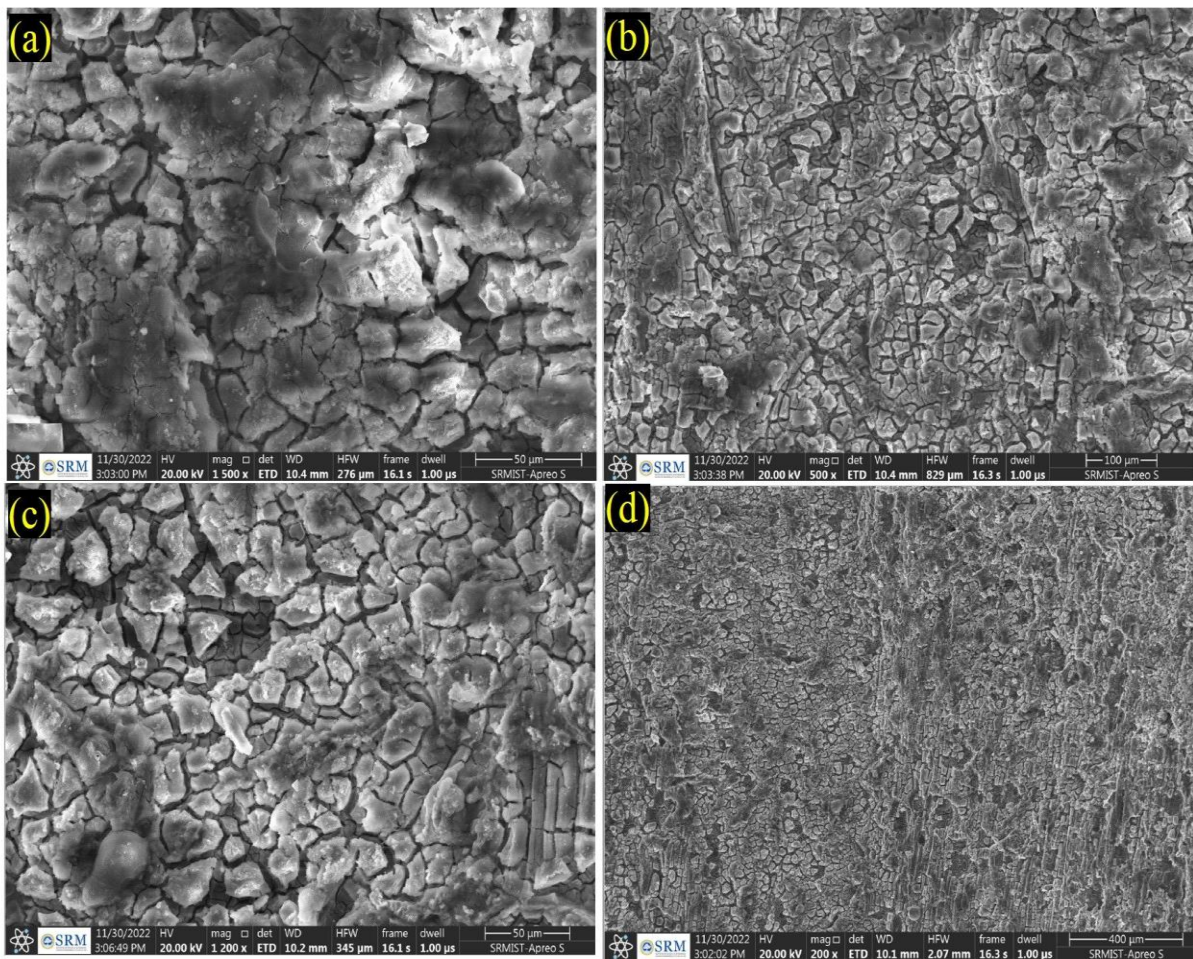


Figure 9. SEM image of different samples

5.6 Experimental validation on DPI

ZE41 is a magnesium alloy during drilling operations was proven under ideal testing conditions. Equation 11 predicts response values and DPI values as a result. Table 7 summarizes the results of the confirmation tests. In the validation trials, the difference between anticipated and actual responses was less than 5%, indicating that the Taguchi models developed for AWJM on ZE41 is a magnesium alloy were acceptable. At initial condition AWJP=150 MPa, SOD=0.5 mm, TS=110 mm/min, MFR=200 g/min, and in optimal condition, AWJP=300 MPa, SOD=1 mm, TS= 72 mm/min, and MFR=400 g/min, the performance of the AWJM process on ZE41 is a magnesium alloy is observed.

$$\gamma_{pred} = \gamma_m + \sum_{k=1}^{nq} (\bar{\gamma} - \gamma_m) \quad (11)$$

Table 7. Experimental Validation

Confirmation	S_R	S_{ZN}	S_A degree
Initial setting	3.40	5.80	9.24
DPI setting	2.98	5.24	8.75
Actual	2.86	4.89	8.62
Improvement (%)	4.02	6.67	1.48

Conclusion

The paper details the parameter design for cutting ZE41 is a magnesium alloy employing the AWJC process. The principal component-based grey incidence (PGI) method was revealed for optimizing and forecasting the best combination of cutting parameters simultaneously. Experiments were conducted using Taguchi's L array. The following are the results of the analysis.

1. The PGI methodology successfully predicted the optimal conditions are $SOD=1$ mm, $TS= 65$ mm/min, $MFR=400$ g/min and $AWJP=350$ MPa.
2. The relative impact of variables in lowering S_R , S_{ZN} , and S_A is investigated using ANOVA statistics on DPI response. Significant variable was AWJP as 44.31%. The other process variables, MFR, SOD, and TS, had a minor impact.
3. During the drilling process, the PGI integrated technique was successfully used to improve the machining condition on ZE41 is a magnesium alloy to lower the S_R , S_{ZN} , and S_A .
4. The confirmation results revealed that the PGI technique improved S_R by 4.02%, S_Z by 6.67%, and 1.48% in the S_A . In addition, other optimization techniques, like genetic algorithms and artificial neural network techniques, could be used to optimize various cutting parameters during abrasive water jet cutting of ZE41 is a magnesium alloy.
5. The SEM analysis shows that the smooth S_R was achieved with a maximum level of AWJP, MFR, and minimum level of SOD and TS.

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