Electrical Discharge Machining of Super Alloys: A Review

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Abstract. In the current scenario, manufacturing industries faces difficulties during machining of engineering materials-metal based, having higher mechanical properties viz. higher strength, toughness and hardness through conventional machining methods. These problems include rapid tool wear, poor surface quality of work piece material and lower stock removal rate. EDM is a single prominent what more lucrative unconventional machining procedure is, finding its prevalent functions in motorized and aerospace industries for machining of harder materials that is super alloys. Super alloys are the heat-resistant category of metals maintaining their elevated potency at superior temperature. The present paper focuses on the past work done by the researchers on machining of super alloys viz. titanium, nickel and cobalt using EDM and Wire EDM process.

1. Introduction
This Electrical Discharge Machining (EDM) is a non-interaction advanced mechanizing progression broadly cast-off by the manufacturers meant for die, mold and automotive components. The process has its wide popularity due to no restrictions for any hardness of materials. The principle mechanism of working in the process depends on the spark energy applied upon the facade of the work-piece material. This erodes the desired materials by means of melt down, vaporization and removal of debris materials to form desired shape and size. EDM is mainly used to machine harder materials [1].

2. Physics of EDM
A voltage difference is second-hand in the middle of the tool-probe and work-piece material (super alloys, die steel and composite). The apparatus electrode in addition to the work-piece raw material would be good quality conductors of heat and electrical energy. As applied voltage is applied and increased between 2 electrodes, a free electrical field is generated on the electrode (negative polarity). This will generate the free electrons, gaining energy and accelerate at high velocity towards the direction of electrode connected to positive polarity.

The electron during movement collides and bombard with the dead molecules of the dielectric fluid. This creates the process of ionization and makes a path for the follow of spark sandwiched between the nearest flank of utensil electrode and tool-piece solid. Thus, finally solid melts plus vaporizes within the dielectric fluid and flushing takes place due the shock waves generated after each pulse on time and secondary flushing attachment.

3. Super Alloys
Super alloys are essential in elevated-temperature functions; they stand additionally recognized as temperature-impervious or extraordinary-temperature alloys. They are particularly beneficial in vapor
turbine, interplanetary automobiles, aircraft, submarine, nuclear vessels, and petrochemical apparatus. Thither stand three grades of super alloys: nickel-constructed, iron-built, and cobalt-built. Super alloys stand source intended for turbine then compressor division of the jet machines, the single constituents towards preserving high-pitched intensity much following uninterrupted contact to tremendously extreme temperatures. Owing to these assets machining of these alloys are complicated. Innovative and alternating approach of machining drove seek to cultivate and routine modern procedures of machining which advertised make use of of EDM process. The development is broadly recognized by the scholars to machine the super alloys [1-4].

4. EDM on Super Alloys
In past researchers worked experimentally Ti-6Al-4V super alloy as a work-piece material and achieves that debris removal rate increases with spark energy. Electrode wears rate reduction around the margin of the electrode and negative polarity for the work-piece greater material removal and lower wear of electrode [1]. Scientists work on the Ti-Al-4V as a work material and gave an idea with results viz.MRR of the blend EDM/USM development is advanced than the orthodox EDM. This assist in improving machining efficiency [2]. In the year 2005 researchers machined the Inconel 601 as a work-piece material and determine that WEDM progression holds exhibited its suitability in the direction of mechanizing Inconel 601 solid underneath appropriate volumetric physical exclusion proportion. Surface toughness rises along through surge of peak-current and cuts in conjunction with the escalation of responsibility element then line stiffness [3]. Inconel-825 work-piece material was cut and accomplishes that an exceptional machined finish is attained by establishing the machine-limitations to the superlative research scrutinized by Taguchi process. The samplings triggered using CNTs have clearer surface finish [4]. In 2012 research was conducted on the Ti-6Al-4V or Inconel 718 and cemented carbide as a work material. It was predicted and was found that particular geometry in case of Ti-6Al-4V either one granulating is the highly price-valuable expertise [5]. Researchers worked in 2013 on the Inconel 718 as a work-piece quantifiable and conclude that in attendance was a 64.8% increase in intensity in material removal-rate and at the equivalent time a 9.52% reduction in coarseness value [6].

In 2013 on the C1023 aeronautical alloy as a work-piece material and achieves that best strictures for low-slung point electrode deteriorate and low erosion period are those that carry composed low intensity, eminent pulse time and trifling servo voltage [7]. In 2013 on the Inconel 718 as a work-piece material and concludes that stimulus of feed rate was very minimal due to the reducing tool geometry, and it impact is more substantial in radial direction [8]. Inconel 718 as a work material was machined and determines that anticipated fuzzy version delivers a extra detailed and easy-going varieties of EDM feedback boundaries for the requisite reactions in this manner to enhance machining circumstances and slash expenses [9].

Ti–6Al–4V super alloy machined as a work material and concludes that convention, thrust force declined with the surge in supply pace. [10]. Polycrystalline diamond work material was machined with observations like high-pitched hardness and excellent wear resistance, PCD materials are extremely tough to be machined [11]. In 2013 on the Inconel 738LC as a work material and concludes that employing ultrasonic backed technique in drilling of Inconel 738LC super alloy creates it feasible to produce profound holes in the super alloy together with depth-to-diameter up to 10µm [12]. The author’s in [13] worked in 2014 on the Inconel 625 as a work material and found that the EDM recast-layer was removed. The authors worked in 2014 on the Inconel 718 as a work material and identified that-all the way through the advancement of a nickel-coated cable the detrimental Cu and Zn contamination may perhaps be diminished [14]. The author’s worked in 2014 on the Inconel 718 as a work material and observed that electrodes of convex bottommost silhouette execute improved than hollow or level summarized rods in standings of
smaller recast-layer, enhanced external texture aimed at unadorned exterior machining and nearer geometry then MRR for hovel training [15].

Incoloy800 super alloy was tested and machined. It was predicted that and found that current and voltage were extremely substantial constraints, whilst pulse-on time and pulse-off time are non-substantial constraints by contemplating ROC reaction [16]. Aerospace material: Ti6Al4V was machined and it was found that hole penetrations of 0.5 mm, CuW electrode wear extends a 25%, and surges to 50% for hovel complexities of 5.5 mm together through conductor diameters of 300 µm [17].

The author’s worked on the Inconel -718 as a work-piece material and observed that the utilization of a traditional tool geometry headed to an unflattering chip pattern and a low wear resistance instigated by sharp tip. The improved tool developed in a decline of the mechanical loads and helped an substantial increase in the chip formation [18]. The author’s Sanjay Gaur, PK Bharti worked in 2015 on the Nickel based super alloy as a work material and investigated that EDD process has been able to machine such complicated to machine materials with enhanced performances. In addition MRR was seen to increase with the aggregate of tool RPM and at same time Ra has also been improved [19].

The author’s worked in 2015 on the Ti-6Al-4V Alloy as a work quantifiable and found that the ever-increasing dielectric rinse out compression (Pd) enhanced the MRR substantially then enhanced the instrument conductor wear degree (EWR) [20].

It was reported by the researchers that higher MRR and low EWR were gained with increased size of crater and recast layer were identified due to increased pulse on time. As recommended by the authors, this may be due to generation of greater thermal energy with increased pulse on time [21].

It has been reported that graphite electrode EDM 3 generated the higher MRR than AF5 electrode [22].

Some studies have been carried out for improving the routine individualities namely, MRR, EWR and surface roughness (SR) of pure titanium alloy of Ø 6.3 × 30 mm, using copper tool electrode having Ø 8x 40 mm [23].

Micro-slot machining studies on cobalt-chrome-molybdenum work piece, of size 20×10×8 mm using copper-tungsten tool electrode (size 0.2×2×5 mm) have also been performed. It was studied that discharge region of machining increased with a discharge current, and decreased with an upsurge of pulse on time [24].

Micro drilling of Inconel-718 alloy partaking thickness 4.76 mm was carried out by using gray relational analysis optimization method. The machining strictures such as release current, pulse period, open voltage, and gyratory rapidity determine their effects on hole taper ratio. The hole taper ratio was seen to surge with an increase of liberation current and thrrob time. As observed by the researchers, the increase in current density increased the heat generation amongst the tool electrode and the work solid. Further, surface defects were also seen on the machined work material for instance blobs of debris, pock marks and liquefied drops. [25]

[26] elucidated machining bulks of up-to-the-minute EDM boring machines predestined intended for boring conserving hovels and diffusors in turbine vanes, decontaminating the procedure dexterity and mechanizing yield of space amalgams, boring of refrigeration cavities and conformation of diffusors can exist unified keen on a solitary advance by exploiting indistinguishable electrode for combined approaches. Investigational conclusions of material removal rate, relative tool wear and surface integrity for EDM drilling and shaping progresses are established.

[27] determined the superlative engaging of controllable process boundaries delimited by designated experimental province to attain satisfactory machining accomplishment. Be obliged to constriction of Taguchi’s optimization viewpoint i.e. the situation cannot unknot multi-comeback optimization conundrum; conception of gratification role partakes striven in this seek to accomplish gratification standards of distinct rejoinders, aiding accretion of multi-retort characteristics hooked on a corresponding specific catalogue.

[28] did untried study near inspecting façades of EDM scheduled on Inconel 718 super alloy by means of Copper tool electrode partakes demarcated in this. Grounded on three manageable scheme variable
quantity viz. crowning expulsion current, beat-on period and slit voltage, experimentations partake remained putative obtainable examine properties proceeding coaxing innumerable routine structures. Furthermore, EDAX scrutiny gets supported out to explore the scale of carbon sub junction on top of the machined exterior as rehabilitated throughout pyrolysis of the dielectric fluid at the same time as accomplishing EDM operation.

[29] designated the paraphernalia of four assorted groupings of dielectric fluid continuously superficial veracity of the recast layer molded throughout elevated rapidity EDM drilling developments existed premeditated; the underpinning machinery of the reorganized layer on nickel alloy is contested by correlating superficial charms of the majority and those of the recast layer by resources of incalculable portrayal approaches. The dielectric fluid through sophisticated electric conductivity was revealed to partake preeminent understanding to the single pulse discharge energy.

[30] designated Powder mixed electrical Discharge Machining shows vivacious situation cutting-edge machining development of roughly identical thought-provoking to machine materials. Petro chemical, chemical rockets partakes remained exploited by way of work piece and mechanizing through commissioning powder mixed electrical discharge machining process (PMEDM).

[31] dealt with augmenting the features for instance current, pulsation on time and pulsation off time in quietude in the direction of to attain the optimum comeback engaging Taguchi practice. These prosecutions are executed in Inconel 625 alloy through copper by way of a conductor. EDM are acceptable aimed at machining stiff constituents for illustration the super alloys, titanium material, etc. through affluence. It has been gained that, the current theatres an energetic location cutting-edge influencing the MRR, maintained by pulse on time and pulse off time.

[32] machined Ti-6Al-4V ELI (Grade 23) with EDM machining procedure take on beat on time, voltage and current by way of the technique limitations. Superficial quality and Material removal rate of apiece one occupation was premeditated. External syllable structure stood proficient on the mechanized exterior to scrutinize deportment of the work piece. Multi reaction Grey Relation Analysis practice was rummaged to develop the course limitations and major bearings subversion was fascinated towards perceive the impression of limits during MRR and superficial coarseness.

[33] designated the machinability influence of monel blend is calculated through fluctuating the strictures of Electrical Discharge Machine (EDM). Material Removal Rate (MRR) and Surface Profile (Ra) stand occupied by way of the reliant on constraints. Towards envisage of the optimal ailment, the experimentations are led by using Taguchi’s L27 orthogonal array. The stimuli of individual sovereign stricture on the conditional on restrictions are scrutinized commissioning multi-functional grey relational analysis by the intention of intensifying MRR with satisfactory level of Ra.

[34], premeditated that innumerable die sinking EDM progression strictures are evaluated thru orientation to feedbacks. The machining strictures estimated are Current (C), Pulse on-time (Ton), Pulse off-time (Toff) and Flushing Pressure (FP). The retort variable quantity pragmatic are Material Removal rate (MRR), Tool Wear Rate (TWR), Surface Roughness (SR) and Radial Overcut (ROC). TAGUCHI L25 orthogonal array is intended on behalf of untried design and satisfactory grained graphite as tool conductor thru conducting tests. Numerous deterioration estimation remains dramatic on all comeback to build mathematical model which are futuristic on practical to envisage the retorts employing optimum constraints.

[35] did experimentations in the direction of acquiring the superlative amalgamation of participation development restrictions such as peak current (IP), open voltage (Vg), pulse-on-time (Ton) & duty factor (τ) for EDM machining of Inconel 718. An orthogonal array of method parameters was perceived, consuming Minitab software for example the arrangement of experiments (DOE). On behalf of solo province of abundant productivity feedback parameters, we use ahead the helpfulness process. Subsequently, we function the Taguchi optimization system to attain obtainable optimum parameter launching for preeminent materials removal rate (MRR), cut electrode wear rate (EWR), and low-down surface roughness (SR).

[36], studied efficiency of dielectric media (conventional EDM oil and distilled water) in the framework of machinability of Inconel 825 aimed at the duration of electro-discharge machining.
this work, machinability is gauged in horizon of material removal proficiency, tool wear rate, and surface integrity of the machined sampling. Learning of surface integrity comprises morphological training as well as investigation of topographical procedures like surface roughness, surface crack density, white layer thickness, foreign material exodus, metallurgical classification sideways with segment variation and sleet of intermetallic compounds and conclusively, micro-hardness tests. Experimental calculations indicate that as contrasted to EDM oil, distilled water unfavorably affects the efficiency in the direction of material removal, and encourages formation rough surface. An important examination is that when EDM oil is used as dielectric media, carbide development is attached to the machined surface due to pyrolysis of hydro-carbon. Period in case of distilled water, its disintegration causes oxide growth at the machined surface instead of carbides.

[37] studied impressions of Cryogenic Treatment (CT) of tool/work piece on machinability of Inconel 825 super alloys. The straightforwardness of machining endured determined in locations of innumerable performance highlights viz. Material Removal Rate (MRR), roughness average (Ra), Surface Crack Density (SCD) and White Layer Thickness (WLT) designed crosswise machined surfaces, determination was also thru to carry out a comparative study on chemical conformation, metallurgical characteristics, residual stress and micro-indentation hardness of the machined specimens found by using NTNW, CTTNW and NTCTW, respectively.

[38] conducted experiments by altering topmost discharge current together through a static attention of MWCNT (0.5 g/l) combined towards kerosene. EDM performance is reviewed in horizon of material elimination efficacy, instrument wear frequency, plus superficial veracity (morphology and topography) of the EDMed sampling. The situation stands decided that by way of contrasted to conformist EDM, usage of MWCNT-assorted dielectric media (0.5 g/l) substantially enhances machining routine.

5. Conclusion
The ancient two eras have perceived the cumulative use of EDM proceeding super alloys. The procedure consumes occasioned in notable enhancement in multifaceted machining complications in problematic-to-machine alloys, succeeding precise deductions can be stressed from the published research work on EDM of super alloys in this review.
1. The submission of EDM process in the machining of nickel base and titanium base alloys has lectured the surface integrity, metallurgical states and topological limitations. Numerous topographies motionless necessity to stand express to for the positive impression of the progression on the business.
2. The practice of electrode material in the machining process of super alloys stood incomplete to solitary uncommon where is a possibility intended for victimization powder metallurgy and composite electrodes for restored consequences in material transference.
3. Several study workings consumes stayed approved obtainable bearing in mind the consequence of discharge current and pulse extent wherever as here is a requirement to study the pulse off-time also for reflecting white layer and surface topography.
4. Literature shortages the mechanism of material transfer from electrode surface and powder deferred in dielectric medium to the surface of work piece.
5. There is possibility of research on super alloys using hybrid EDM as lone ultrasonic and magnetic force abetted electric discharge machining have been described consequently distant.

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