# Optimization of Wire Electrical Discharge Machining Process Parameters for Al7075/$Al_2O_3$/SiC Composite Using Aspect Ratios of Taguchi Method, Taguchi-Pareto and Taguchi-ABC Methods

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**Abstract.** *Aspect ratio determination has recently become a new way of evaluating the optimal parametric setting using the Taguchi method and following the orthogonal array-signal-to-noise ratio-response table route. Unfortunately in the machining domain, there is no account of any computations made using completely aspect ratios. But available records show a blend of direct and aspect ratios. To deviate from the extant literature practice, this article proposes a situation where all the factors are considered as aspect ratios for the determination of optimal process parameters in a wire electrical discharge machining process. Aspect ratios are integrated into the evaluation scheme at the factor-level stage where the ratios of each direct factor are obtained relative to the others. The values obtained are then transformed in an orthogonal matrix format to the signal-to-noise ratios, which are summarized as averages in the response table to obtain the optional parametric settings. The optimal parametric settings for the Taguchi method is* $(A/B)_1(A/C)_1(A/D)_1$*which is interpreted as 2.00 for a pulse on-time/pulse off time, 2.00µs/A for a pulse on-time/current and 1.00µsmin/ m for a pulse on-time/ wire drum speed. The ranks of the factors after the Taguchi analysis are A/C(pulse on-time/current) ranked 1st, A/B (pulse on-time/pulse off time) ranked 2nd and A/D (pulse on-time/ wire drum speed) ranked 3rd. Furthermore, the optimal parametric settings using Taguchi Pareto's method is* $(A/B)_1(A/C)_1(A/D)_1$*which is interpreted as 2.00 for a pulse on-time/pulse off time, 2.00µs/A for a pulse on-time/current and 1.00µsmin/ m for a pulse on-time/ wire drum speed. The ranks of the factors after Taguchi-Pareto analysis are A/D (pulse on-time/ wire drum speed) ranked 1st, A/C (pulse on-time/current) ranked 2nd and A/B (pulse on-time/pulse off time) ranked 3rd. Now, focusing on the results of group A alone in the Taguchi-ABC method, the optimal parametric settings for group A are* $(A/B)_1$ $(A/C)_1(A/D)_1$ *which is interpreted as 2.00 for pulse on-time/pulse off time, 2.00 µs/A for a pulse on-time/current and 1.00 µs min/m for a pulse on-time/ wire drum speed. The ranks of the factors after Taguchi ABC analysis for Group A are A/C(pulse on-time/current) ranked 1st, A/B (pulse on-time/pulse off time) ranked 2nd and A/D (pulse on-time/ wire drum speed) ranked 3rd. The synergy between the aspect ratios and the orthogonal arrays helps the process engineers/operators of wire. EDM machines practically and effectively optimize the process and select the most promising aspect ratios and values for further decisions. The aspect ratios respond to the methods and offer the first step towards attaining a sustainable wire EDM process.*

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## 1. Introduction

The purpose of this study is to optimize the process parameters of the wire electrical discharge machining (WEDM) during the processing of Al7075/$Al_2O_3$/SiC by deploying the Taguchi method, Taguchi-Pareto and Taguchi-ABC methods. Before now, producing the Al7075/$Al_2O_3$/SiC using the conventional method consumes substantial time and labour costs. This is coupled with significant scraps that threaten the environment as environmental waste, when discarded and when not occupying an enormous workshop space. Associated with this is noise pollution from the machining process. However, conventional machining has failed because of the inability of the process to machine the Al7075/$Al_2O_3$/SiC due to its chemical and mechanical attributes, making it difficult to machine despite the commercial availability of the Al7075/$Al_2O_3$/SiC [1].

As automobile technology and related systems continue to focus on magnesium alloys for improved durability, extended lifespan and lightweight components, there is a drive for the adoption of magnesium alloys as the fundamental material for component manufacture [2],[3],[4]. Nonetheless, guided by the knowledge of the machining literature, the gap between the usage of magnesium alloys in automotive components and the vast availability of magnesium alloy materials matched against the projected potential usage is still too wide [2],[4].

Authors such as Muniappan et al. [5] and Yuan et al. [6] are few among those that recognize the existence of this gap and responded in publications to examine the composition of magnesium alloy [5] and the density/specific strength analysis of magnesium alloy [6]. This implies the need for optimization of the properties of the magnesium alloy obtainable by understudying the process parameters of the alloy. Yet, this aspect is not fully studied in the literature. Consequently, optimization schemes must be developed to equip machine operators and process engineers with strategies capable of tackling the optimization and prioritization difficulties in the machining of Al7075/$Al_2O_3$/SiC using the wire electrical discharge machining process.

To the best of the authors' knowledge, extremely few studies have analyzed the optimization of WEDM process parameters of Al7075/$Al_2O_3$/SiC using the Taguchi method and its variants because of the difficulty in the machining process [7],[8],[9],[10]. For most machining planning activities, including the Al7075/$Al_2O_3$/SiC, optimization of the process is still being done using intuition and the experience of the operator and process engineers [7]. However, since the available installed capacity of the WEDM process is very limited, exploiting the full capacity of processes while machining Al7075/$Al_2O_3$/SiC is not feasible. Using the available method of intuition and experience, the need for sustainable machining operations cannot be met for the following reasons: (1) several products and variants are being demanded in machining, making the machining chain complicated and leaving the process engineer with huge machining tasks that are best managed through optimization; (2) it is difficult to manage the machining tasks of Al7075/$Al_2O_3$/SiC given the limited resources available for the system; (3) the subjective perception of optimization by using intuition and experience instead of the objective use of mathematical methods of Taguchi and its variants promotes local optimum findings instead of global optimum discovery. Consequently, it is extremely urgent to build up optimization schemes for the processing of Al7075/$Al_2O_3$/SiC using the WEDM process.

The chief novelties and contributions of this article are as follows. The establishment of efficient, methods (Taguchi-Pareto and Taguchi-ABC) for the WEDM process of the Al7075/$Al_2O_3$/SiC is a frontline novelty in the processing of magnesium alloys in the WEDM domain. Second, the proposed methods exhibit a two-featured mechanism of concurrent optimization of process parameters and prioritization of parameters either through the Pareto or ABC interfaces. Third, the Al7075/$Al_2O_3$/SiC is utilized as a case material to verify the approaches and demonstrate their effectiveness and superiority over intuition and the experience of the operator.

Furthermore, this article proposes two new methods of Taguchi-Pareto and Taguchi-ABC with optimization and prioritization enablement to take advantage of the streamlining capability of the Pareto scheme from the 80-20 rule perspective. It also takes advantage of the ABC classification scheme that establishes three grades of importance as the A, B and C groups in process optimization.

An argument is offered here that if optimization is ignored while operating the wire electrical discharge machining process for the Al7075/$Al_2O_3$/SiC sub-optimal values may be obtained. Furthermore, ignoring the choice of the best parameter to decide on resource distribution decisions increasingly worsens the sub-optimal results being dependent on intuition and the machining process cannot achieve the full potentials of the Al7075/$Al_2O_3$/SiC and machining process. Therefore, to experience the optimum and full potential of the system, Taguchi methods, especially with the twin mechanism of optimization and prioritization present in the Taguchi-Pareto and Taguchi-ABC methods should be instituted in the WEDM process. This will capture the key process parameters (aspect ratios) of Pulse on time/Pulse off time, Pulse on time/Current and Pulse on time/wire drum speed**.** Unfortunately, despite the awareness of machining centers on optimization and the knowledge that guidance on attaining the best results is achievable only by introducing mathematical methods, there is still a generally slow attitude of operators and process engineers in using optimization methods, particularly the Taguchi-Pareto and Taguchi-ABC methods.

The proposed study in this article has substantial significance to practice by the way of transforming the Al7075/$Al_2O_3$/SiC into useful components. It assists the process engineer in the planning process, aiding the optimization of the WEDM process variables and this determines the deficiency in the literature, which to date is unattended to. Furthermore, it sheds light on the important characteristics of the methods such that the process engineer could implement the methods for the best results. Besides, by instituting the concept of optimization and prioritization using the Taguchi-Pareto and Taguchi-ABC methods, a method not previously deployed in the WEDM literature, the attraction of scholars to pursue solving the problem from different perspectives is created.

Furthermore, in the related scientific journals on engineering manufacture, including journals with a focus on industrial engineering, optimization of industrial processes has begun a recent call for discussions and applications in machining, particularly non-conventional machining is strongly desired and emphasized in call for papers. However, as a growing number of discussions are observed, the use of simplified methods for industrial use is also an emphasis.

# 2. Literature Review

The review of literature in this article falls under the following modules: (1) Wire electrical discharge machining (2) Thermal and electrical properties (3) Surface (wear, corrosions and fracture) attributes and (4) analysis using the Taguchi method. For the Al7075/$Al_2O_3$/SiC, authors agree on the uniqueness of properties of the Al7075/$Al_2O_3$/SiC which stimulated its ranks to the top position. However, this attribute needs to be operated at optimal points, hence, the use of the Taguchi-Pareto and Taguchi-ABC methods may be relevant in application to the Al7075/$Al_2O_3$/SiC material. For the second module, wire electrical discharge machining, the authors agree that conventional machining fails to satisfy the machining demands of difficult-to-machine materials such as the Al7075/$Al_2O_3$/SiC. Thus, they opined that non-conventional machining schemes such as the wire electrical discharge machining satisfy the requirement of this important alloy. The module on the thermal and electrical properties of the material emphasizes the relationship of the concepts of dielectric fluid, heat flux and high voltage on the machine material outcomes in surface characteristics and general material attributes such as elimination of micro-cracks, micropores, eliminating brittleness and attaining good ductility of processed materials. The next module, surface declared the evolution and control of surface damages such as wear, corrosion and fracture). The last module is the analysis using the Taguchi method, which displays the success route pursued in achieving optimization using the Taguchi method with and without the combination of other methods such as the analysis of variance. Subsequently, each of these modules is discussed in detail as follows:

## 2.1 The Al7075/$Al_2O_3$/SiC Hybrid Composite

Over the years, material scientists and engineers have discovered the huge potential of using the Al7075/$Al_2O_3$/SiC hybrid materials in various applications where wear and corrosion are predominant problems if not controlled. In Sreedhar [10], the wear rate for the Al7075/$Al_2O_3$/SIC hybrid composite was investigated with three principal parameters of interest, namely volumetric loss of material, weight loss per sliding distance and the frictional coefficient measurement of the material under dry sliding experiments. It was concluded that the composite (Al7075/$Al_2O_3$/SiC) exhibited superior wear resistance compared with the Al7075 matrix alone.

Furthermore, nanoparticulate experimentation, which was emphasized in Sreedhar [10] is addressed again in the article by Suresh et al. [8]. However, the later author showed interest in corrosion monitoring. The later authors characterized reinforced Al7075 with SiC on one side, reinforced Al7075 with $Al_2O_3$ on the second and unreinforced Al7075 alloy on the third side. While the three corrosive media applied are the 3.5% sodium chloride (NaCl), sulphuric acid ($H_2SO_4$) and hydrochloric acid (HCl), it was concluded that better corrosion resistance was exhibited by the two reinforced alloys of Al7075 + $Al_2O_3$ and Al7075 + SiC as opposed to only unreinforced Al7075 alloy. Furthermore, research on Al7075/$Al_2O_3$/Sic/mg composite focused on measurable such as the hardness of the composite, tensile strength analysis and compressive strength of the material. It was reported that growth in all the mentioned parameters exists on adding both $Al_2O_3$ as well as SiC reinforcements to the Al7075 alloy.

Besides, while still investigating both mechanical behaviour and wear characterization, Kumar et al. [11] deployed the stir casting process in experiments and Taguchi's L9 orthogonal array as the analytical tool to optimize the process parameters. The feasibility of using the approach with an acceptable range of wear and mechanical attributes of the Al7075/$Al_2O_3$/SiC hybrid composite was reported. By continuing on wear characterization, Raghavendra et al. [9] analyzed the experimental results of wear experiments of Al7075 reinforced with Sic and Al7075 materials. The authors reported that the total tribological characteristics of the prepared material were enhanced by adding the Sic and $Al_2O_3$ reinforcements. Also, Kumar et al. [12] reported on experiments concerning the wear, tensile strength, and hardness properties of Al6061-SiC and Al7075/$Al_2O_3$ composites. It was concluded that the SiC introduced to Al6061 alloy and $Al_2O_3$ dispersed in Al7075 alloy were influential in improving the composite's tensile strength. Furthermore, Rajesh et al. [13], conducted, wear experiments using the Al7075 as a matrix and each of SiC and $Al_2O_3$ as reinforcements. It was reported that improvement in wear resistance of the reinforced Al7075 material prevailed.

From the foregoing, the literature review on the Al7075/$Al_2O_3$/SiC hybrid composite revealed the major interest of researchers only in mechanical characterization, wear and corrosive studies and extremely fewer studies on the machining attributes of the material as evidenced by the only study by Lal et al. [7]. Further, there has not been any case in the electrical discharge machining literature where the Taguchi-Pareto and Taguchi ABC methods under the mechanism of aspect ratio consideration were established.

## 2.2 Wired Electrical Discharge Machining

Manufacturing has taken a different dimension entirely different from what it used to be when it all began. This change has even progressed to convectional machining and currently to the non-conventional machining system such as the wire electrical discharge machining (WEDM). This is due to its high degree of dimensional accuracy, ease in carrying out complex and intricate designs, precision, tolerance, and better surface finishes. Response characteristics such as surface roughness (SR), cutting speed (CS), Kerf width (KW), Metal removal rate (MRR) and many others have been considered by many authors who used various input parameters to optimize the WEDM processes. Muniappan et al. [5] made claims that for good functional characteristics and increase in productivity to be achieved in a WEDM process, optimum selection in machining parameters must be made a requirement. Lal et al. [7] in their work on optimizing WEDM process parameters for Al7075/$Al_2O_3$/SiC hybrid composite concluded that out of the parameters that were considered for the work, pulse on time was the most important parameter which contributed the highest to the achievement of the desired surface roughness and kerf width. Chalisgaonkar and Kumar [14] worked on the process capability of EDM parameters to achieve high-quality output characteristics e.g. surface roughness (SR), Metal removal rate (MRR), wire wear ratio (WWR) etc. although they focused on surface roughness and machined workpiece dimension.

Nayak and Mahapatra [15] confirmed the various parameters that are considered in achieving the desired response characteristics or output for every machining operation that is carried out. They came up with a concept in the analysis of the WEDM process for metal removal which they termed an inclined discharge angle. They gave a proposition for enhancing efficiency in WEDM operations which included controlling the wire tension and the power discharge rate during the process. They adopted Taguchi's design of experiment by looking closely at the various parameters that are involved in the WEDM process to improve the outcome characteristics and present their work to relieve the associated challenges of surface roughness, angular error and cutting speed.

Chaudhari et al. [16] conducted an experimental investigation on how to optimize some selected WEDM parameters to improve certain external characteristics of multi-walled carbon nanotubes such as it performs during machining (in other words MRR) and to improve its surface appearance (SR), they utilized an advanced version of TLBO algorithm with no parameters to optimize the various responses and the best solution in which they arrived at an optimized single objective output maximum rate of metal removal to be MRR of 0.5262 g/min with current at 5A, pulse on time at 110µs, pulse off time at 1 µs, and with a multi-walled carbon nanotube amount of 1.27g/min. For a minimum rate of metal removal, they arrived at 1 A current, 1 µs of pulse on time, 24 µs of pulse off time and a multi-walled carbon nanotubes amount of 1 g/L.

Sonawane and Kulkarni [17] merged Taguchi's method with variance analysis on a nimonic 75 alloy material in optimizing some selected WEDM parameters. These are the pulse on time, pulse off time, servo voltage, current, wire tension and the wire feed rate to determine the output characteristics of the surface roughness (SR) and the rate of removing metal (MRR). Their achieved optimized parameter values with the best output characteristics are pulse on-time 110µs, pulse off time 51µs, servo voltage 40 V, current 230 A, wire tension 8 g and the wire feed rate 5 m/min. ANOVA shows that the major determining factor in the actualization of the desired aim was pulse on time with a contribution of 52.9%. Chalisgaonkar and Kumar [14] study the optimization and analysis of processes in a wire electric discharge machining of pure titanium material, in which they used some selected input parameters to investigate the process capability of some characteristics in machining such as the surface roughness (SR) and the machined workpiece dimension (MWD). Nayak and Mahapatra [15] attempt to optimize a taper cutting operation in a WEDM process. They adopted a style of utility approach to optimize six process parameters, which include the taper angle, the pulse duration, the discharge current, the wire tension, the thickness, and the wire feed. They were able to arrive at a single equivalent response which they called the overall utility index. Finally, they introduced the analytical hierarchical process in determining the weight of each output which they verified using the analysis of variance. Ai and Quan [18] showed how titanium reacts with AZ91 magnesium alloy to alter its mechanical properties and rate of corrosion. The microstructure of the magnesium alloy is being refined when the weight between 0.1 to about 0.5 %. They also noted that the structural phase of the alloy is changed from a coarse form to a uniform grain. With the addition of about 0.4% of titanium, the tensile strength increases to about 197Mpa and an elongation of 6.9%. And finally, high corrosion resistance is achieved.

## 2.3 Thermal and Electrical Properties

Chaudhari et al. [16] noted that the rate at which heat is dissipated within the dielectric fluid increased due to the MWCNTs' high thermal conductivity. This leads to a further reduction in the plasma heat flux within the electrode and results in reduced micro-cracks, micropores, and melted material on the machined surface. When electrical pulses decrease, smaller craters are formed resulting from the discharge channel expansion. They proved that MWCNT concentration makes it possible for the spark to be uniformly distributed and for debris on the machined surface to be properly flushed. Yuan et al. [6] observe that when the AZ91 magnesium alloy is subjected to about eight rounds of equal channel angular pressings at high voltage, the hardness of the material increases. After being heat-treated in a solution, the molecular structure of the alloy is homogenized thereby almost eliminating the brittleness characteristics in the material and attaining good ductility. For the strength of the material (between 205 to 233 MPa), it became better when subjected to heat treatment at an increased temperature above room temperature (between 100° and 150°C).

## 2.4 Surface (Wear, Corrosion and Fracture)

Chaudhari et al. [16] analyse a WEDM process and the debris re-deposition on the machined surface, which can be eliminated to a great extent to produce a thin layer of RLT in the WEDM process when mixed with powder. The extent of surface finish is increased while the thickness of the RLT is reduced as a result of the thermal properties of the MWCNTs which absorb a tangible quantity of heat emitted during the machining process.

## 2.5 Analysis using the Taguchi Method

Danthal et al. [19] optimized multiple objectives using a modified Taguchi method on a robot spray painting. They considered certain process parameters to arrive at a target outcome. These are process indicators (film adhesion, surface roughness, and thickness variation). Harudin et al. [20] worked on the selection of optimization features of an unnatural bee colony. They improved the speed of the analysis and reduced the cost and the demand on the computer during the analysis by using Taguchi's method of orthogonal array plus the artificial bee colony to arrive at the best feature selection. Penteado et al. [21] used Taguchi's method to improve o the turning process of a nimonic 80A superalloy. They arrive at a final value of 5mm for the flank wear.

Mishra and Gangele [22] optimized the wear width of a tool flank for AISI 1045 steel using Taguchi's approach and analysis of variance. They discovered that selected machine parameters have the capacity of influencing the wear width of the flank tool of a tungsten carbide cutting tool during the machining of AISI 1045 steel. They concluded that cutting speed happens to be the most influencing parameter amongst other parameters. Kast [23] applied significant testing to Taguchi's approach to quality control. Krishnaiah and Shahabudeen [24] applied experimental design and Taguchi's approach. Das et al. [25] used a six sigma Taguchi's approach in trying to enhance the output quality of the process, using galvanized iron as the sample material. They found out that the mean values and standard deviation of run data are much lesser when compared to Taguchi's run. Rajesh and Venkatesh [26] used Taguchi's approach and Pareto's analysis of variance in micro EDM drilling. They conclude that when parameters are low, they produce a low surface roughness, with the capacitance value being the most potent parameter which influences others on the outcome of the surface roughness. Ajibade et al. [27] combined Taguchi and Taguchi Pareto's approach to explaining the transfer and evacuation of waste from the cell composite material. They were able to achieve the aim of the experiment which is to produce a format that manufacturers can adopt to get an optimized result and cut costs during the design of composite materials.

Rao et al. [28] utilized the Taguchi method in identifying some key concepts that are part of the current formulation. Khan et al. [29] optimized the parameter of the WEDM process using a Taguchi-based grey relational analysis and made an investigation on the process, using grade SS304 Stainless Steel as the sample material. Pulse on time was found to be the most influencing parameter in achieving quality surface roughness and kerf width after several analyses. Galvan [30], in applying parametric optimization to machine design, discovered that optimizing the parameters of a machine process can solve some pending issues in a design process. They conclude that there are other methods through which you through can who can march and be impressed. Gowd et al. [31] conducted experiments using known parameters such as the pulse on time, pulse off time, water pressure and wire tension and were able to conclude by developing a quantifiable relationship between the input parameters and the output characteristics in the WEDM process.

Singh and Pradhan [32] used the Taguchi method and response surface methodology in optimizing the WEDM process on AISI D2 Steel. They found out that when the material removing rate and cutting speed are maximum, the surface roughness is minimum and vice versa. Nayak and Mahapatra [15] in optimizing a taper cutting operation, utilized a utility concept approach and the Taguchi method to present a highlight of the multi-response approach to finding out what is the best value of the selected process parameters in a WEDM system in taper cutting activities. They concluded by using the analysis of variance to discover what the effect of each parameter would be on the taper cutting process. Sonawane and Kulkarni [17] optimized a WEDM process combining the Taguchi L27 approach and principal component analysis. They improved the composite primary component from 1.2013 to 1.2443 and used the scanning electron microscope to view the microstructural appearance of the machined part.

Sudhakara and Prasanthi [33] applied Taguchi's method to determine the best surface roughness in a WEDM of powder metallurgical cold worked Vanadis-4E tool steel. Saedon et al. [34] worked on the optimization of titanium alloy via orthogonal array and grey relational analysis in a WEDM. They made a recommendation for ideal parameters needed to achieve the required output when machining a titanium-based alloy. Gao et al. [35] optimized the process for a PCD micro-milling tool and discovered a huge difference in input parameter value which affects the output results such as cutting speed. This is required to achieve surface roughness and the metamorphic thickness of the layer which is considered during a finishing operation. Schwade [36] analysed the constant electrical signal for technological development in WEDM. They concluded that although the series of experiments needed to arrive at the desired result can be lengthy the number of tests can be reduced.

## 2.6 Observations Arising from the Review of Literature

After the conduct of the literature review revealed in the previous section, the following observation is made, which could be useful inputs in deciding on what aspect of research to pursue based on the study gaps.

1. In the wire EDM research domain, three groups of parameters may be mentioned here: frequently used, less frequently used and seldom used. In this context, many articles frequently used pulse on time, pulse off time and current as parameters. Current has been referred to as discharge current. The less frequently used parameters are cutting speed, wire tension, wire feed and wire thickness. However, the seldom-used parameters in the opinion of the present authors are angular error and servo voltage. Now, considering the output, the responses that are frequently used in the literature are the surface roughness and material removal rate. But the wire wear ratio appears in the less frequently used category while the machined workpiece dimension is seldom used as a response to the wire EDM system.
2. The several techniques used to evaluate the wire EDM system include the utility approach [15], analytic hierarchy process (AHP) [15], TLBO algorithm [16], ANOVA [17] and Taguchi method [17].
3. The materials used in wire EDM, which have been previously reported are Al7075/$Al_2O_3$/SiC hybrid composite [7], pure titanium [14] and titanium and AZ91 magnesium alloy [18].

4. The thermal and electrical properties of materials have been studied.
5. The aspect of the surface analysis of materials has been studied and this includes wear, corrosion and fracture studies.
6. The literature survey indicated that extremely small research initiatives associated with the Al7075/$Al_2O_3$/SiC hybrid composite have been launched in the machining literature. Yet the composite is a key component of industrial materials in automobile and allied industries [7].
7. For the newly introduced aspect ratios within the factor-level table for the evaluation of optimal parametric setting, the dominant method is to integrate direct factors and aspect ratios [37]. There is the complete absence of aspect ratios alone within the test framework of factor-level for the evaluation of optimal parametric settings.
8. Though the literature suggests aspect ratios, there are no insights about extending the discussion to economic parameters. Yet the sustainability of machining systems strongly hinges on economic functions and evaluations.
9. With aspect ratio conception in optimal parametric setting determination, rigorous computations on ratios are initiated. However, no discussions have been made to include other functional inputs integrated with aspect ratios such as square and cube root of aspect ratios and direct factors for the optimal parametric factor determination. Furthermore, the sensitivity analysis of these aspect ratios has not been examined.

In the previous literature discussed in this article and the introductory aspect of this work, a research gap regarding the present study was indicated. However, it is implicit that the extremely negligible introduction of aspect ratios to replace direct factors in the factor-level platform to compute the optimal parametric setting for the aspect ratios using the Taguchi techniques. To date, only two research papers have been reported; the first publication is due to Oke and Adekoya [38] while the second paper is by Adegoke and Oke [37]. Although the latter paper is in the turning domain and strongly related to the wire EDM study currently analyzed in this article, the earlier paper is largely in only the maintenance engineering-oriented article considered aspect ratios in totality and displayed direct factors in computations but this is outside the machining research domain. Thus, at present, no efforts were invested by scholars in the wire EDM research domain to completely replace the direct factors with aspect ratios. Consequently, this article attempts to account for the aspect ratios in the factor-level platform of the optimal parametric determination route by a complete displacement of the direct factors by the aspect ratios. Thus, the introduction of aspect ratios in the factor-level platform of the Taguchi technique while machining the Al7075/$Al_2O_3$/SiC hybrid composite under the wire EDM scheme is the novelty of this article. This article then finds important usefulness in the parametric determination of the wire EDM process for hybrid composite materials.

# 3. Methods

In this section, the methods employed to transform the experimental data into results are discussed. First, an introduction to the conceptualization of the project, which aims to transform the Al7075/$Al_2O_3$/SiC hybrid composite into a processed work material through the electrical discharge machining process, is made. Then the Taguchi method in the wine EDM process is explained in procedural details. This is followed by some explanations of the procedure for the Taguchi-Pareto and Taguchi-ABC methods used in the wine EDM process with specific attention given to the Al7075/$Al_2O_3$/SiC hybrid composite material.

## 3.1 Conceptualisation and Processing of A17075/$Al_2O_3$/SiC using Wire Electrical Discharge Machining

In this section, the authors attempt to explain the process that the Al7075/$Al_2O_3$/SiC alloy is subjected to during the electrical discharge machining process. There are several stages involved in this. However, to achieve a quick review of the electrical discharge machining process, a schematic is presented, Fig. 1, which consists of stages from the conceptualization of the component upon which the A17075/$Al_2O_3$/SiC alloy is made to the final stage. It flows from the top part downwards, from the product conceptualization to the electrical discharge machining of the A17075/$Al_2O_3$/SiC alloy. The first stage of Fig. 1 is the conceptualization stage where every design needs to be conceptualized. This is the phase in which the process engineer pictures what is to be achieved. Every design starts to form the designer's imagination. The final issue in the conceptualization is to establish what is to be designed or modified. The modification of a component could be, for instance, the body of a car. In this case, the process engineer tries to achieve a situation where a lighter body and a very tough body are obtained. Since it is understood that the heavier the materials of the body of a car, the more the consumption of energy.

So, the process engineer wants to achieve efficiency with the use of the right material for the auto panel, for instance. This idea brought about the issue of conceptualization, which is the first box in the flow diagram. Thus, the concept of trying to reduce the weight and changing what material is being used earlier. That is, steel metal sheets are replaced with A17075/$Al_2O_3$/SiC alloy, for instance. Usually, steel metal sheets are heavy and the idea is to bring in the A17075/$Al_2O_3$/SiC alloy, which is lighter than steel. This idea also applies to a wide range of moving machines such as aircraft and automobiles. Now, the researchers move to the next stage, which is the material section where A17075/$Al_2O_3$/SiC alloy is selected to serve the purpose and remedy the challenge the researchers are attempting to solve. In selection, a wide range of materials is considered such as aluminum, and composites. Here, the authors considered some factors to knock out other materials to remain only aluminum alloy, which is more easily available than composites. It weighs lower than composites. Also, it appears to cost less than the amount composites are sold. Furthermore, the next stage is the design and CAD design. Furthermore, the next stage is design and CAD designing. By design, a rough sketch is prepared and this could be transmitted into the computer-aided design in an electrical discharge machine. The two stages of design and CAD design work hand in hand in that if there are some designs on paper, the machine, through the assistance of the operator and process engineer should be able to transmit them into CAD design.

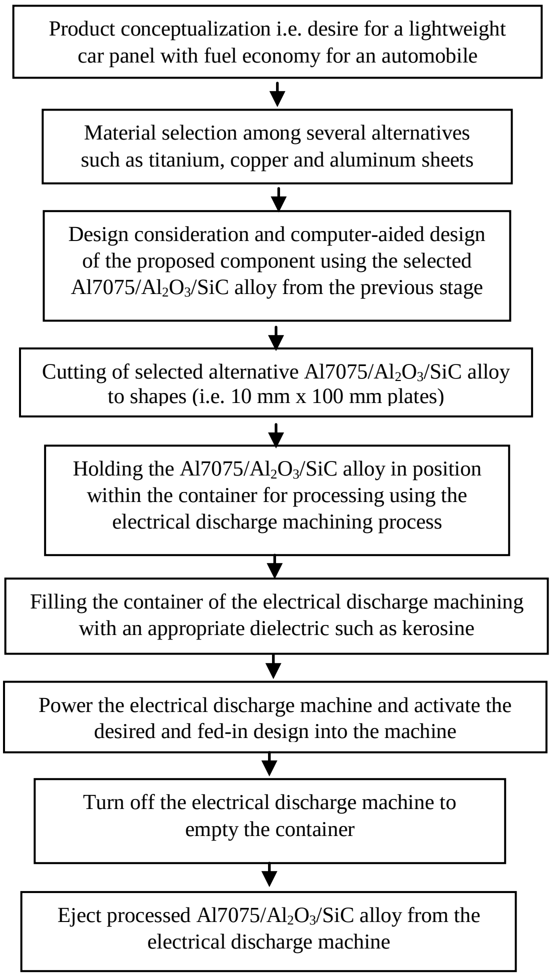


**Fig. 1** Conceptualisation and processing of the Al7075/$Al_2O_3$/SiC alloy using wire electrical discharge machining

First, before doing a CAD, the research should sketch and factor in the openings and doors on the components as well as the holes in the particular design. After this, Notice that from the designs and CAD stage, the electrical discharge machining comes in. To the best of the authors' knowledge, many of the electrical discharge machining systems are programmable. From here, the researcher proceeds to the cutting of the workpiece to shape. For instance, what is required by the operator to work on is probably a 400 x 400cm worksheet and the available size is 1square meter. Here, there is a need to cut the metal sheet to shape so that it can fit into the container where the final machining is to be carried out.

After this, the authors proceed with a portable workpiece that can be worked upon that can be handled by the EDM machine. Then the authors proceed to the next stage, which is holding the workpiece in position inside the container for the electric discharge machine. As the workpiece is in position using a high level of precision, then it is understandable that the process engineer could achieve up to 100% of the design being carried out. Notice that if there is a fault in holding the workpiece in position, then there will be an error in the processed component, at the end of the work. After holding the workpiece in position, inside the electrical discharge, the filling of the container with a dielectric fluid such as kerosene is done. At this stage, the material, which had been held in place, is submerged in an electric field. This condition applies to the workpiece or material for the electric discharge machine to take place. Then, the EDM machine is powered and the design process is initiated. Notice that the design was done in the third stage. Then initiate the design process. Notice that this is just like the start and stop the process. The start entails giving a command for a machine to start the design that is on the electric discharge machining systems, which had been programmed earlier. As the EDM reached the end of the design program, the machine automatically stops in obedience to the command. Then the next stage is to turn off the EDM and empty the dielectric field in the container. This tallies the researcher to the next stage, which is to eject the finished work. This finished work is ready to be used. Fortunately, the EDM process does not need a secondary machining process such as filing, counter-boring or smoothening of edges, etc.

## 3.2 Taguchi Method in Wire EDM Process

In this article, the wire EDM process is considered and the focus is the optimization of the process parameters while machining the Al7075/$Al_2O_3$/SiC hybrid composite. The Taguchi method in its novel application of aspect ratios to completely replace direct factors for the factor-level table platform is considered. But, the wire EDM process is a huge volumetric processing unit for expensive and sometimes difficult-to-machine materials such as the Inconel series. It has frequent usage in would and die-based manufacturing systems when multiple blanking punches and extrusion dies are worked on. The wire EDM is versatile, extending from prototype development through distinct value-adding stages, to full production runs. Although material wastage is not a problem for the process, labor and other input resources still generate waste through elevated setup times, reworks and scrap generation thereby increasing the cost of wire EDM production. To reduce these costs and enhance the quality of wire EDM's output, the Taguchi method has its place in achieving transformation for the system. Initially developed to control the quality of products, in its applied form to the wire EDM process, the Taguchi method is initiated to optimize the parameters of the wire EDM process, mainly the aspect ratios such that the best parameters may be established for further decision making in wire EDM process. Although the founder of the Taguchi method, Genichi Taguchi, elevated the design principles above the manufacturing process, in this article design is not considered as solely manufacturing principles are discussed and variance elimination is pursued regarding the aspect ratios for efficient decision making in the wire EDM process.

Furthermore, out of the three criteria of signal to noise ratios, the smaller-the-better criterion (STB) is shown here, Equation (1) [39],

$$STB = -10 \log \frac{1}{n} \sum_{i=1}^{n} y_i^2 \quad (1)$$

Here, the symbol $y_i$ means the same as the value of the parameter for every count while $n$ symbolizes the total number of parameters.

Equation (1) works on the mechanism of increasing the system's benefits when smaller values of each parameter are obtained and mapped from the orthogonal arrays to the signal-to-noises. Thus, the decision-maker concludes that the values are transformed through a logarithm system into signal-to-noise ratios. First, the parametric values are squared and then averaged based on the number of parameters for each experimental trial. Then the logarithm of the value is obtained and finally multiplied by-10.

From the three criteria of signal to noise ratios, the larger-the-better criterion (LTB) is revealed here, Equation (2) [39],

$$LTB = -10 \log \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \quad (2)$$

here, $n$ and $y_i$ are the same as earlier stated in the description of the STB criterion.

Equation (2) has similarities in computational mechanism to Equation (1) but with the difference of taking the reciprocals after squaring the values obtained for each parameter. The outcomes are summed up and averaged. The results are multiplied by -10 after obtaining its logarithm. Equation (2) works on the mechanism of increasing the benefit of the system as larger values of each parameter are obtained and mapped from the orthogonal matrix to the signal-to-noise quotients. In this instance, the decision-maker in the wire EDM system concludes that the values of a parameter assuming a large dimension will benefit the wire EDM system.

Out of the three criteria of signal-to-noise ratios, the nominal-the-better criterion (NTB) is indicated here, Equation (3) [39],

$$S/N = -10 \log 10 \ y_i^2 / s^2 \quad (3)$$

here,

$y_i$ shows the characteristics of the performance identity $i$.
$n$ reveals the number of experimental trials
$s^2$ shows the variance of the data

Equation (3) is the nominal-the-best structure, working on the mechanism in-between the smaller-the-better and the larger-the-better criteria. It means that neither the smaller-the-better criterion nor the larger the better influences it. The variance of the values of parameters is the main statistical measure with which Equation (3) works.

The need for Equations (1), (2) and (3) is to provide surrogate outputs with which an input-transformation-output process is replicated for the wire EDM process being modeled with the feedback is attained to know if progress is made by the system or not in this context, the wire EDM is divided into two sub-systems, each with a complete framework of the input-transformation and output scheme, these sub-systems are the signal-to-noise subsystem comprising only of the factors (i.e. aspect ratios) and levels as the inputs, while the orthogonal arrays are the transformation phase and the output phase is the computed signal-to-noise ratios, which could be either negative or positive values. Next, the second subsystem is the response table subsystem where the output of the first subsystem and signal-to-noise ratios are the starting inputs of the second sub-system. The transformation stage is the average signal-to-noise ratios, which are taken as the averages of the specified orthogonal arrays mapped to specific signal-to-noise ratios for each parameter being optimized. A second part of the transformation process is the delta values. These are the differences between the honest and highest averages of the signal-to-noise ratios which provide the direction to establishing the order among the values of the delta values for each factor as first, second and third position as in the example of the wire EDM process being analyzed. The outputs of this second sub-system are the optimal parametric settings (OPSs) and values of parameters. The OPSs are the interpreted values of the highest average signal-to-noise values for each parameter in the response table, which are mapped to specific locations in the initial factor (aspect ratios) - level table experimental data obtained from the literature.

In this article, the signal-to-noise ratio is a dominant measure of performance for the wire EDM parameters as it was found to efficiently compare the level of useful power to the noise power level. The wire EDM operates on pulses, for instance, these pulses may be normal or abnormal when it is normal, the quality of such pulses is desired otherwise such pulses are rejected and understood if the chances of any pulse in the wire EDM system are analyzed. It is known that any wire EDM pulse may finally occur as normal and acceptable or abnormal in the specific categories of short circuit discharges, arc and open. If analyzed by a pulse classifier and counter, then the ratio of each kind may be recorded for further analysis. Consequently, for the aspect ratios, sufficient information may be obtained on their usefulness within the Taguchi techniques framework as one studied the degree of positiveness of the SNR, measured in decibel (dB). A number in the response table for the

Taguchi method is the same as the Taguchi-Pareto method and higher than that of the Taguchi-ABC method. It implies that the Taguchi method and Taguchi-Pareto methods give superior specifications as they appear to be highly advantageous in information content compared with non-advantageous data from the Taguchi-ABC method using the wire EDM system.

## 3.3 Taguchi-Pareto Method in Wire EDM Process

The Pareto analysis has succeeded in science and engineering as a straightforward method to assist the process engineer and operator of the wire EDM system in evaluating the aspect ratios and then prioritizing them after optimization with the Taguchi method. It accomplishes this task by weighing the most positive values of the signal-to-noise ratios within the response table against one another and then finalizing the most positive values as the choice aspect ratio for decision making. Usually, the factor (aspect ratio) that emerges as being superior to others is given the utmost attention in planning and implementation purposes in the wire EDM process. Usually, the 80-20 rule is applied, which means that often, most 20% by volume of parameters (aspect ratios) account for 80% of the value of the system's output.

Next, a further criterion of signal-to-noise ratios is shown in Equation (4), and is relevant to the Taguchi-Pareto method only [39],

$$\text{S/N} = -10\log_{10}(1/n\sum_{i=1}^{n} P_{80-20}y_i^2) \tag{4}$$

Here, $y_i$ could be stated as the smaller-the-better criterion. Nonetheless, if the larger the better is appreciated, then the $y_i^2$ is converted to a reciprocal, $n$ reveals the experimental trials. However, the S/N shows the signal-to-noise ratio for the system being assessed while the $P_{80\text{-}20}$ could be achieved as previously stated.

Equation (4) is referred to as the Taguchi-Pareto methodical framework based on the 80-20 rule of Pareto analysis. The need for the equation is to streamline the experimental trials into fewer items that capture the most essential based on the cumulative signal-to-noise values and the least essential items (experimental trials) are abandoned as they are counted as non-essential to the parametric value optimization and selection goal of the wire EDM process. If analyzed based on the system philosophy, the inputs are the aspect ratios and level table, the transformation of the first subsystem takes place through the choice of an orthogonal matrix and the outpoint is the signal-to-noise quotients. Using the Pareto scheme, the second subsystem starts from the signal-to-noise ratios and the transformation is the reduction of the number of experimental trials via an 80-20 rule of Pareto analysis. The pruned experimental trials are now the output of the subsystem. The mechanism of the Taguchi-Pareto method works on the computation of the aspect ratios to establish the factor-level framework. Then the orthogonal array is formulated, afterwards, the signal-to-noise ratios and computed and the Pareto 80-20 rule is implemented to obtain a reduced experimental count.

## 3.4 Taguchi-ABC Method in Wire EDM Process

In this method, the experimental trials and by extension the parameters (aspect ratios) are divided into three distinct groups A, B and C based on the values of the signal-to-noise ratio according to grades of 0-69% for C, 70-80% for B and 81-100% for the A group. The classification scheme is the first step to establishing which of the aspect ratios in the wire EDM process are the most essential. This implies that management attention to resource control and distribution should be concentrated on the best parameters (aspect ratios).

Next,, the computational procedure of the Taguchi-ABC method is shown in Equation (5) [27],[39]:

$$\text{S/N} = -10\log_{10}(1/n(ABC)\sum_{i=1}^{n} y_i^2) \tag{5}$$

Here, $y_i$ could be stated as the smaller-the-better criterion. Nonetheless, if the larger the better is appreciated, then the $y_i^2$ is converted to a reciprocal, $n$ reveals the experimental trials. However, the S/N shows the signal-to-noise ratio for the system being assessed while the ABC could be achieved as previously stated.

Equation (5) is referred to as the Taguchi-ABC method's computational scheme. The need for this equation is to provide a classification scheme where the strong, middle strength and weak strength experimental trials are identified and are afterwards transferred into the choice of parameters of similar strength classification. It is based on the principles of operation of the ABC inventory classification scheme where the A group signifies the strong and the most important class of parameters for the wire EDM process. Further, the B group is the middle strength parameter and is the next in strength to the A group. Lastly, the C group is the weak group, the last set of parameters in the group. The working mechanism of the Taguchi-ABC method is similar to that of the Taguchi-Pareto method described earlier. However, the difference is that instead of restricting the analysis to the 80-20 rule, where 20% of the items take the 80% by value, the Taguchi-ABC method works on 0-69% for the C group, 70%-80% for the B group and 81%-100% for the A group.

# 4. Results and Discussion

In this section, analysis is conducted on the obtained literature experimental data, which yields results on the aspect ratio analysis. However, before this discussion, a subsection that justifies the case study, using the combined Al7075/$Al_2O_3$/SiC composite is given:

## 4.1 A Case for the Al7075/$Al_2O_3$/SiC Hybrid Composite

Considering the effect of sliding distance on the wear performance of Al7075, a component of the hybrid composite (i.e. Al7075/$Al_2O_3$/SiC), the cumulative wear loss experienced by the Al7075 material subjected to the diverse speeds ranging from 600 to 800rpm in an upgrade of 100rpm between measures, the following observation was reported by Karthigeyan [40]. It was revealed that a nearly linear pattern of wear loss as the sliding distance grew linearly occurred. But the linear trend appears as the best among the negative outcomes. From the foregoing, the Al7075 appears a strong wear-resistant material and further improves its utility by combining it with other materials with outstanding wear behaviour such as the $Al_2O_3$ and SiC. The literature promotes the addition of elements of Si and declared success at its wear test. For instance, Karthigeyan [40] reported the concurrence of wear test results with the work of Skolianos and Kattamis [41] and Akbulut et al. [42]. These two authors reported the wear rates of 0.096, 0.043 and 0.027g.mm$^{-1}$ for the Al+7%Si, Al+12%Si, and Al+14%Si, respectively, using the 15N loads. The connection of this fact with the present study is that Si is a component of the material, and SiC is used in the hybridized component. Thus, it is expected that Si combined with C together with $Al_2O_3$ will radically transform the wear performance, thereby justifying studying the Al7075/$Al_2O_3$/SiC hybrid composite.

## 4.2 General

In the extant literature, several authors have evaluated the optimal parametric settings for different systems, including the wire EDM process. However, the consensus idea is to use the direct factors in the factor-level table definition. But in this work, the aspect ratios are used. One of the things that motivated the authors to use aspect ratios is to look for ways to best optimize most of the parameters that are used in the present work on wire EDM process research pursuit. This is to bring out novelty in the application of the Taguchi techniques to the experimental data drawn from the literature. This novel approach of the complete introduction of aspect ratios in the factor framework of the factor-level table instead of combined direct factors and aspect ratios suggested by Adegoke and Oke [37] is advancement in the optimal parametric setting literature. It adds value as it comprehensively tests the validity of the aspect ratio introduction in optimal parametric setting development. In this work, the first parameter in the experimental data utilized in this work, pulse on time, was used to divide the rest (i.e. each pulse on time, pulse off time, current and wire drum speed). Thus, in this article, to obtain the aspect ratios, the first parameter divided by it yields one, which could be ignored in aspect ratio computation.

The first parameter is used to divide the second parameter, pulse off time to obtain the aspect ratio pulse on-time/pulse off time. Next, the first parameter is used to divide the third direct factor, current to yield the aspect ratio of pulse on-time/current. Furthermore, the first parameter is used to divide the fourth direct factor, wire drum speed (Table 1).

| Aspect ratios | Level 1 | Level 2 | Level 3 |
|---|---|---|---|
| A/B | 2.00 | 2.50 | 2.67 |
| A/C (μs/A) | 2.00 | 2.50 | 1.67 |
| A/D (μs)(m/min) | 1.00 | 1.67 | 2.00 |

A - Pulse on time (μs), B - Pulse off time (μs), C - Current (A), D - Wire drum speed (m/min), A/B - Pulse on time/Pulse off time, A/C - Pulse on time/Current (μs/A), A/D - Pulse on time/ Wire drum speed (μs)(m/min)

**Table 1** Wire EDM process aspect ratios and levels (original data obtained from [7])

Next, the L27 orthogonal array is used (Table 2).

Now, in applying the orthogonal array, the aspect ratios are inspected. But the signal-to-noise criterion is decided upon, which is one or combinations of the following: smaller-the-better, larger-the-better or nominal-the-best. Thus, for the four aspect ratios in this work, the signal-to-noise ratio criterion adopted from the three available options is the smaller the better. The reason for adopting this criterion is that it is found that by lowering the ratios, improvement in the system performance is achievable. The best results are achieved from this deployment exercise. To start with, the factor-level table is explored for the aspect ratios and these values are translated through the orthogonal array framework into other values from the parameters to a single value known as the signal-to-noise ratio. Then, the averages of the signal-to-noise ratios are obtained from the following scheme. First, three columns, with each in the interest of each aspect ratio were laid out. Notice that the authors did not have a fourth column as they considered pulse on time/pulse on time to be null. Then, for level 1, the authors obtained the average by finding the sum of the mapped signal-to-noise values and dividing by the total number of items. Notice that the Minitab has been used to generate and arrange these values such that for each level and aspect ratio the averages could be easily obtained. For example, if one is considering level 1, indicated by 1, the corresponding value of the signal-to-noise ratio is picked. This is done for all the values associated with level 1 and the average is obtained. Thus, whenever any value on level 1 tallies with the values on the signal-to-noise ratio, it is picked. The group of values is averaged. This is done for all levels. Next, the optimal parametric setting is obtained (Table 3).

| | Orthogonal array | | | Aspect ratios (translated) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Expt. No. | A/B | A/C (µs/A) | A/D (µs) (m/min) | A/B | A/C (µs/A) | A/D (µs) (m/min) | S/N ratios | %Cumulative S/N ratios | Pareto's decision | ABC rating |
| 1 | 1 | 1 | 1 | 2.00 | 2.00 | 1.00 | -4.7712 | 2.65 | | C |
| 2 | 1 | 1 | 1 | 2.00 | 2.00 | 1.00 | -4.7712 | 5.29 | | |
| 3 | 1 | 1 | 1 | 2.00 | 2.00 | 1.00 | -4.7712 | 7.94 | | |
| 4 | 1 | 2 | 2 | 2.00 | 2.50 | 1.67 | -6.3775 | 11.47 | | |
| 5 | 1 | 2 | 2 | 2.00 | 2.50 | 1.67 | -6.3775 | 15.01 | | |
| 6 | 1 | 2 | 2 | 2.00 | 2.50 | 1.67 | -6.3775 | 18.55 | | |
| 7 | 1 | 3 | 3 | 2.00 | 2.67 | 2.00 | -7.0218 | 22.44 | | |
| 8 | 1 | 3 | 3 | 2.00 | 2.67 | 2.00 | -7.0218 | 26.34 | | |
| 9 | 1 | 3 | 3 | 2.00 | 2.67 | 2.00 | -7.0218 | 30.23 | | |
| 10 | 2 | 1 | 2 | 2.50 | 2.00 | 1.67 | -6.3775 | 33.77 | | |
| 11 | 2 | 1 | 2 | 2.50 | 2.00 | 1.67 | -6.3775 | 37.30 | | |
| 12 | 2 | 1 | 2 | 2.50 | 2.00 | 1.67 | -6.3775 | 40.84 | | |
| 13 | 2 | 2 | 3 | 2.50 | 2.50 | 2.00 | -7.4036 | 44.95 | | |
| 14 | 2 | 2 | 3 | 2.50 | 2.50 | 2.00 | -7.4036 | 49.05 | | |
| 15 | 2 | 2 | 3 | 2.50 | 2.50 | 2.00 | -7.4036 | 53.16 | | |
| 16 | 2 | 3 | 1 | 2.50 | 2.67 | 1.00 | -6.8007 | 56.93 | | |
| 17 | 2 | 3 | 1 | 2.50 | 2.67 | 1.00 | -6.8007 | 60.70 | | B |
| 18 | 2 | 3 | 1 | 2.50 | 2.67 | 1.00 | -6.8007 | 64.47 | | |
| 19 | 3 | 1 | 3 | 2.67 | 2.00 | 2.00 | -7.0218 | 68.37 | | |
| 20 | 3 | 1 | 3 | 2.67 | 2.00 | 2.00 | -7.0218 | 72.26 | | |
| 21 | 3 | 1 | 3 | 2.67 | 2.00 | 2.00 | -7.0218 | 76.15 | | |
| 22 | 3 | 2 | 1 | 2.67 | 2.50 | 1.00 | -6.8007 | 79.92 | | |
| 23 | 3 | 2 | 1 | 2.67 | 2.50 | 1.00 | -6.8007 | 83.70 | OUT | A |
| 24 | 3 | 2 | 1 | 2.67 | 2.50 | 1.00 | -6.8007 | 87.47 | | |
| 25 | 3 | 3 | 2 | 2.67 | 2.67 | 1.67 | -7.5333 | 91.64 | | |
| 26 | 3 | 3 | 2 | 2.67 | 2.67 | 1.67 | -7.5333 | 95.82 | | |
| 27 | 3 | 3 | 2 | 2.67 | 2.67 | 1.67 | -7.5333 | 100.00 | | |

Note: A - Pulse on time (µs), B - Pulse off time (µs), C - Current (A), D - Wire drum speed (m/min), A/B - Pulse on time/Pulse off time, A/C - Pulse on time/Current (µs/A), A/D - Pulse on time/ Wire drum speed (µs)(m/min)

**Table 2** Taguchi's Orthogonal arrays, factors and signal-to-noise ratios

| Level | A/B | A/C (µs/A) | A/D (µs)(m/min) |
|---|---|---|---|
| 1 | -6.0568* | -6.0167* | -6.1242* |
| 2 | -6.8606 | -6.8606 | -6.7628 |
| 3 | -7.1186 | -7.1186 | -7.1490 |
| Delta | 1.0617 | 1.1018 | 1.0249 |
| Rank | 2nd | 1st | 3rd |

A - Pulse on time (µs), B - Pulse off time (µs), C - Current (A), D - Wire drum speed (m/min), A/B - Pulse on time/pulse off time, A/C - Pulse on time/Current (µs/A), A/D - Pulse on time/ Wire drum speed (µs)(m/min)

**Table 3** Taguchi SN ratio response table

| Level | A/B | A/C (µs/A) | A/D (µs)(m/min) |
|---|---|---|---|
| 1 | -6.0568* | -6.0568* | -6.1242* |
| 2 | -6.7054 | -6.7054 | -6.3775 |
| 3 | -6.9112 | -6.9112 | -7.0763 |
| Delta | 0.8544 | 0.8544 | 0.9521 |
| Rank | 3rd | 2nd | 1st |

A - Pulse on time (µs), B - Pulse off time (µs), C - Current (A), D - Wire drum speed (m/min), A/B - Pulse on time/pulse off time, A/C - Pulse on time/Current (µs/A), A/D - Pulse on time/ Wire drum speed (µs)(m/min)

**Table 4** Taguchi-Pareto SN ratio response table

In summary, the optimal parametric settings for the work done is $(A/B)_1(A/C)_1(A/D)_1$which is interpreted as 2.00 for pulse on-time/pulse off time, 2.00µs/A for a pulse on-time/current and 1.00µsmin/ m for a pulse on-time/ wire drum speed. Also, the delta values for the pulse on-time/pulse off time, for a pulse on-time/current, and pulse on-time/ wire drum speed are 1.0617, 1.1018 and 1.0249, respectively. Furthermore, the ranks of the factors after the Taguchi analysis are A/C (pulse on-time/current) ranked 1st, A/B (pulse on-time/pulse off time) ranked 2nd and A/D (pulse on-time/ wire drum speed) ranked 3rd. For the Taguchi-Pareto method, the process of the Taguchi method is repeated except that 80% of the data is captured (Table 2) and the final table is obtained as Table 4.

For the Taguchi Pareto method, the optimal parametric setting is $(A/B)_1(A/C)_1(A/D)_1$which is interpreted as 2.00 for a pulse on-time/pulse off time, 2.00µs/A for pulse on-time/current and 1.00µsmin/ m for pulse on-time/ wire drum speed. Next, the delta values for the pulse on-time/pulse off time, for a pulse on-time/current, and pulse on-time/ wire drum speed are 0.8544, 0.8544 and 0.9521, respectively. Also, the ranks of the factors after Taguchi analysis are A/D (pulse on-time/ wire drum speed) ranked 1st, A/C (pulse on-time/current) ranked 2nd and A/B (pulse on-time/pulse off time) ranked 3rd. For the Taguchi-ABC method, the response table is shown in Table 5.

| Level | A/B | A/C (μs/A) | A/D (μs)(m/min) | Group |
|---|---|---|---|---|
| Level 1 | -5.7811 | -5.5744 | -6.1242 | **A** |
| Level 2 | -6.5891 | -6.5891 | -6.3775 | |
| Level 3 | -6.8007 | -6.8560 | -7.0218 | |
| Delta | 1.0195 | 1.2816 | 0.8976 | |
| Rank | $2^{nd}$ | $1^{st}$ | $3^{rd}$ | |
| Level 1 | -7.0218 | -7.0218 | - | **B** |
| Level 2 | -7.4036 | -7.4036 | - | |
| Level 3 | -7.0218 | -7.0218 | -7.0854 | |
| Delta | 0.3819 | 0.3819 | 0 | |
| Rank | $1^{st}$ | $1^{st}$ | $3^{rd}$ | |
| Level 1 | - | - | - | **C** |
| Level 2 | -7.4036 | -7.4036 | -7.5333 | |
| Level 3 | -7.5333 | -7.5333 | -7.4036 | |
| Delta | 0.1297 | 0.1297 | 0.1297 | |
| Rank | $1^{st}$ | $2^{nd}$ | $2^{nd}$ | |

A - Pulse on time (μs), B - Pulse off time (μs), C - Current (A), D - Wire drum speed (m/min), A/B - Pulse on time/pulse off time, A/C - Pulse on time/Current (μs/A), A/D - Pulse on time/ Wire drum speed (μs)(m/min)

**Table 5** Taguchi-ABC SN ratio Response table

The Taguchi ABC Analysis is divided into three groups, namely A, B and C. For group A, the optimal parametric settings for the work done in group A are $(A/B)_1(A/C)_1(A/D)_1$ which is interpreted as 2.00 for a pulse on-time/pulse off time, 2.00 μs/A for pulse on-time/current and 1.00 μs min/m for pulse on-time/ wire drum speed. Next, the delta values for group A for the Taguchi ABC are the pulse on-time/pulse off time, for a pulse on-time/current, and pulse on-time/ wire drum speed are 1.0195, 1.2816 and 0.8976, respectively. The ranks of the factors after Taguchi ABC analysis for Group A are A/C (pulse on-time/current) ranked $1^{st}$, A/B (pulse on-time/pulse off time) ranked $2^{nd}$ and A/D (pulse on-time/ wire drum speed) ranked $3^{rd}$. For group B, **t**he optimal parametric settings for the work done in group B are $(A/B)_{1,3}(A/C)_{1,3}(A/D)_3$ which is interpreted as 2.00/2.67 for a pulse on-time/pulse off time, 2.00/1.67 μs/A for pulse on-time/current and 2.00 μs min/m for pulse on-time/wire drum speed. Next, the delta values for group B for the Taguchi ABC are the pulse on-time/pulse off time, pulse on-time/current, and pulse on-time/ wire drum speed are 0.381874942, 0.381874942 and 0, respectively. Also, the ranks of the factors after Taguchi ABC analysis for Group B are A/B (pulse on-time/pulse off time) ranked $1^{st}$, A/C(pulse on-time/current)ranked $1^{st}$ and A/D (pulse on-time/ wire drum speed) ranked $3^{rd}$. Furthermore, the optimal parametric settings for group C are $(A/B)_2(A/C)_2(A/D)_3$ which is interpreted as 2.50 for pulse on-time/pulse off time, 2.50 μs/A for a pulse on-time/current and 2.00 μs min/ m for pulse on-time/wire drum speed. Then, the delta values for group C are the pulse on-time/pulse off time, for a pulse on-time/current, and pulse on-time/wire drum speed are 0.1297, 0.1297 and 0.1297, respectively. Also, the ranks of the factors after Taguchi ABC analysis for group C are the A/B (pulse on-time/pulse off time) ranked $1^{st}$, A/C (pulse on-time/current) ranked $2^{nd}$ and A/D (pulse on-time/ wire drum speed) ranked $2^{nd}$.

## 4.3 Comparison of the Current Study with the Literature

In this article, the signal-to-noise ratios (SNRs) obtained in both the current article and previous studies utilizing the various method of Taguchi, Taguchi-Pareto and Taguchi-ABC have been used as a measure of comparison of the performance of the present study's results. Consequently, in the relatively short joining of aspect ratios as a measure of determining the optimal parametric settings for a set of parameters, the two articles that have been published so far, namely Oke and Adekoya [38] and Adegoke and Oke [37] are used as a basis of assessment of the context of the wire EDM process and as a tool for promoting its index use in engineering it should be noted that the first application of aspect ratios as a foundation element of the Taguchi techniques was demonstrated in maintenance engineering (i.e. [38]) and following this introduction, Adegoke and Oke [37] extended its use to turning experiment. Notwithstanding, the novelty of the two articles are different, while Oke and Adekoya [38] utilized a complete aspect ratio group to displace direct parameters, Adegoke and Oke [37] argued that the combination of direct factors and aspect ratios as introductions to the factor-level table of the Taguchi techniques framework is feasible. Thus, from the ongoing discussion, a comparison of the results from Oke and Adekoya [38] is taken first. Here, the present authors compare the SNR of the Taguchi method, and the Taguchi- ABC method in both Oke and Adekoya [38] as well as the present study.

In Oke and Adekoya [38], at the response table determination and the specification of the optimal parametric setting, Table 5 (S-N response table ($\beta = 0.5$) revealed that for the Taguchi method, DTM/PDF ranks first among the aspect ratio factors and optimally exist at level1 with an SNR of -59.3487 dB. This result, compared with the present study of the wire EDM process reveals a response table showing the first position for the A/C (MS/A) aspect ratio at level 1 with an SNR of -6.0167 dB. But based on literature judgment, the SNR obtained in the present study's parameters performs better than those of Oke and Adekoya [38] in that they carry less noise with them in the production of signals for the wire EDM process. Next, the present authors judged the performance of the current parameters using the Taguchi method in both Oke and Adekoya [38] and the present study but $\beta = 1$ noticed that Oke and Adekoya [38] did not consider Taguchi-Pareto and Taguchi-ABC methods. Therefore, $\beta = 1$ Table 10 (S-N response Table 1 $\beta = 1$) revealed that for the Taguchi method, DTM/PDF aspect ratio still ranks first (similar to the result obtained $\beta = 0.5$) among the aspect ratios and optimally exists at level 1 into an SNR of – 31.6332 dB. By comparing this result with the present outcome of the Taguchi method, which is as previously stated for the A/C (MS/A) aspect ratio at level 1 with an SNR of -6.0167 dB, the SNR obtained in the current study is higher than what obtained in Oke and Adekoya [38] and then the present study's parameters are superior in performance than those of Oke and Adekoya [38]. It implies that the parameters for the present study carry less noise than those of Oke and Adekoya [38], at the response table determination and specification of the optimal parametric setting, Table 15(S-N response table $\beta = 3$) revealed that the Taguchi method, DTM/CDF aspect ratio ranks first among the aspect ratio factors and optimally exists at level 3 with an SNR of -51.6112 dB. Consequently, this result, compared with the present study of the wire EDM process reveals a response table showing the first position for the A/C (MS/A) aspect ratio at level 1 with an SNR of -6.0167 dB. However, judging from the literature knowledge that parameters with higher SNRs are superior to those with lower SNRs, it is concluded that for the comparison $\beta = 3$ of Oke and Adekoya [38], the current study parameters are superior to those of Oke and Adekoya [38] in that they hold lesser noise than those of Oke and Adekoya [38].

From the foregoing, the present study results regarding the SNR have been compared with those of Oke and Adekoya [38] such that the present study's Taguchi SNR results were weighted with those of the Taguchi method in the Weibull distribution parameters of $\beta = 0.5$, 1 and 3. Thus, in all the three instances considered, the present study proved superior to the literature results present study is less noise-generating than those of the literature [38]. It means that the present study aids less noise in its processing of results than that of the literature by Oke and Adekoya [38]. Furthermore, the present authors argue that it is better to compare the results of the present context in a wider context than for the maintenance case considered. In this context, the results of the second report on the aspect ratio used in the domain of turning operation (i.e. [37]) are relevant to this model on the wire EDM process and are compared for further validation of the scheme reported in the present study. Notwithstanding, the wider range of comparison of the present study with the literature exceeds those limited to the Taguchi method but also the Taguchi method, Taguchi-Pareto method and Taguchi- ABC method. In Adegoke and Oke [37], at the response table determination and specification of the optimal parametric setting, Table 4 of the article revealed that for the Taguchi method, V direct factors rank first among the considered factors and optimally exist at level 1 with an SNR of -25.05280 dB. This result, when compared with the present study of the wire EDM process, reveals a response table showing the first position for the A/C (MS/A) aspect ratio at level 1 with an SNR of -6.0167 dB. By judging based on better performance of the SNR, the present study obtains higher performance than what obtains in Adegoke and Oke [37] since the parameters in the present study are associated with less noise than those in Adegoke and Oke [37].

Next, the present authors judged the performance of the current parameter using the Taguchi-Pareto method in both cases. Since the parameters in the present study are associated with less noise than those in Adegoke and Oke [37]. Next, the present authors judged the performance of the current parameter using the Taguchi-Pareto method in both cases in Adegoke and Oke [37], Table 4 revealed that for the Taguchi-Pareto method, v direct factor still ranks first among the combined factor and aspect ratios and optimally exists at level 1 with an SNR of -25.0529 dB. By comparing this result with the present outcome of the Taguchi-Pareto method (Table4), the A/D ($\mu$ms m/min) aspect ratio ranks first among the aspect ratios and optimally exists at level 1 with an SNR of -6.1242 dB. By comparing this result with the present outcome of Taguchi- Pareto [37] stated earlier, the SNR obtained in the current study is higher than what was obtained in Adegoke and Oke [37]. This implies that the parameters for the present study carry less noise than those of Adegoke and Oke [37].

Besides, in Adegoke and Oke [37], at the response table determination and specification of the optimal parametric setting, Table 5a (Taguchi-ABC SN ratio response table) revealed that for the Taguchi-ABC method (group A), V direct factor ranks first among the aspect ratio direct factor combination and optimally exists at level 2 with an SNR of -28.57 dB. Corresponding, this result, compared with the present study of the wire EDM process reveals a response table showing the first position for the A/C (MS/A) aspect ratio at level 1 with an SNR of -5.5744 dB. However, judging from the literature knowledge that the parameter with high SNRs is superior to those with lower SNRs, the present researchers assert that for the comparison of the Taguchi-ABC (group A) in both Adegoke and Oke [37] and the present study, the parameters of the present study in wire EDM are superior to those in Adegoke and Oke [37]. The justification is that the latter holds more noise in the parameters than in the earlier work.

From the above discussion, the Taguchi results of Taguchi, Taguchi-Pareto and Taguchi-ABC methods were compared for Adegoke and Oke [37] and the present study favors the present study in all cases. In summary, based on the two comparisons of Oke and Adekoya [38] versus the present study and Adegoke and Oke [37] and the current study, six cases were considered. All six cases favor the present study and promote it as having superior reduced noise content to the parameters in the two other referenced papers.

# 5. Conclusion

In this article, the principal contribution is the introduction of aspect ratios into the factor-level table for the optimal parametric setting determination using the Taguchi method. The aspect ratios ignored the classical direct factors that are usually employed to determine the optimal parametric setting and used the relative values of the direct factors from one to another. From the analysis carried out in the previous section of this article, the optimized values of the aspect ratios were obtained and the three important elements of the final results, namely the delta values, ranks and optimal parametric settings were determined. In summary, the following conclusions are made from the work:

1. The use of complete aspect ratios to displace the direct factors or the combination of direct factors and aspect ratios is feasible in the use of the Taguchi method to evaluate the optimal parametric setting of wire EDM process parameters in the processing of Al7075/$Al_2O_3$/SiC hybrid composites.
2. The optimal parametric settings for the Taguchi method is $(A/B)_1(A/C)_1(A/D)_1$which is interpreted as 2.00 for a pulse on-time/pulse off time, 2.00µs/A for pulse on-time/current and 1.00µsmin/ m for a pulse on-time/ wire drum speed.
3. The optimal parametric settings using Taguchi Pareto's method is $(A/B)_1(A/C)_1(A/D)_1$ which is interpreted as 2.00 for pulse on-time/pulse off time, 2.00µs/A for pulse on-time/current and 1.00µsmin/m for pulse on-time/wire drum speed.
4. On the results of group A alone in the Taguchi-ABC method, the optimal parametric settings for group A are $(A/B)_1(A/C)_1(A/D)_1$ which is interpreted as 2.00 for pulse on-time/pulse off time, 2.00 µs/A for pulse on-time/current and 1.00 µs min/m for a pulse on-time/ wire drum speed.

After completing this study, it is understood that the following are important scope for future work:

1. Proposed research may target the possibility of introducing aspect ratios in complete replacement of direct factors but in which these aspect ratios are products of themselves and some economic indicators such as the inflationary factor, interest rate or their combinations. This may be conducted under the three methods of Taguchi method, Taguchi-Pareto method and Taguchi-ABC method.
2. The aspect ratios developed in the serial no. 1 discussion may be replaced with a combination of direct factors, aspect ratios, exponential, cubic and quadratic functions while other conditions in the research could be maintained as described.
3. If serial no. 2 ideas are implemented, there are bound to be several computations that may be challenging to solve by hand. Consequently, coding of the procedure may be attempted to ease this computational challenge and promote the use of the method among process engineers and operators in the wire EDM process plant.
4. Other techniques such as the analytical hierarchy process and fuzzy analytic hierarchy process could be used to replace Taguchi techniques to solve the problem.

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