e-ISSN: 2685-4090 http://ojs.uajy.ac.id/index.php/IJIEEM

Optimizing Turning Parameters for The Turning Operations of Inconel X750 Alloy with Nanofluids Using Direct and Aspect Ratio-based Taguchi Methods

Ridwan Majekodunmi Adegoke [1] **and Sunday Ayoola Oke** [2*]
[1,2] Department of Mechanical Engineering, University of Lagos, Lagos, Nigeria
Email: adegokeridwanmajekodunmi@gmail.com, sa_oke@yahoo.com

*Corresponding author

ABSTRACT

For the turning process, the computation of optimal parametric settings for parameters has been traditionally achieved using standard parametric values, but comparative values between the standard parameters have been ignored. But these aspect ratios reveal some evaluation dimensions that account for robust measurement schemes that promote enhanced effectiveness of the process. To address the issue, an aspect-ratio-based mechanism has been introduced to optimize the turning parameters in three Taguchi methodical variants of classical Taguchi, Taguchi-Pareto, and Taguchi-ABC methods. A total of twelve alternatives were developed, with each alternative containing three standard parameters and two aspect ratios since only three standard parameters are involved in the evaluation. The evaluation of parameters in non-prioritized and prioritized forms was considered for each alternative. The Taguchi method accounts for the non-prioritized method, while Taguchi-Pareto and Taguchi-ABC methods are the prioritized parametric structures. The delta values and ranks across the prioritized and non-prioritized parameters were evaluated by their mean values. The optimal parametric settings were evaluated for all alternatives in the prioritized and non-prioritized forms of evaluation. The results, using literature data, confirmed the feasibility of using the approach. The outcome of the methods is in enhancing the planning scheme for the turning operation. The benefit of the study is an enhanced analysis of turning operation's improvements and estimation of related economic advantages through turning resources conservation.

DOI: https://doi.org/10.24002/ijieem.v3i2.5457

Keywords: Turning process, Taguchi method, aspect ratios, optimization, prioritization.

Research Type: Research Paper

Reference to this paper should be made as follows: Adegoke, R.M. & Oke, S.A. (2021). Optimizing Turning Parameters for The Turning Operations of Inconel X750 Alloy with Nanofluids Using Direct and Aspect Ratio-based Taguchi Methods. ***International Journal of Industrial Engineering and Engineering Management, 3*****(2), 59-76.**

1. INTRODUCTION

The objective of this research for the turning operation parametric optimization and selection is to establish a reference of valid associations and factors to optimize the parameters of Inconel X-750 alloy subjected to nanofluid lubrication, using the aspect ratios together with direct parameters in Taguchi methods. The variants of Taguchi methods utilized are the classical Taguchi method, Taguchi-Pareto, and Taguchi-ABC methods (Ajibade et al., 2016; Okanminiwei and Oke, 2020; Ajibade et al., 2021). The purpose is to estimate better the optimized parameters values and the need to turn operations at global instead of local optimal (Gunantara, 2018; Elsheikh et al., 2021). This includes a review of literature and information update regarding typical industrial practices to control turning operation's capacity and use of resources regarding the Inconel X-750 alloy (Kannan and Kannan, 2018; Marsh, 2018; Venkatesan et al., 2018, Venkatesan et al., 2019b). Efforts will include studies of standard and aspect ratios in various alternatives numbering twelve. This article uses the aspect ratios of parameters to explain the optimization mechanism involved in turning Inconel X750 alloy when determining the optimal parametric settings, ranking, and delta values of factors using the Taguchi methods (Ujiie et al., 2001; Cardwell, 2015). The method involves Taguchi's classical method, Taguchi-Pareto and Taguchi-ABC methods

(Ajibade et al., 2016; Okanminiwei and Oke, 2020; Ajibade et al., 2021). The aspect ratio phenomenon, introduced successfully in the material forming research domain some decades ago, is adopted to advance the study of Taguchi's optimization method. The study with a prediction that the concept will sharpen the performance analysis terrain of the Taguchi method in the next few years.

Notwithstanding, the adoption of aspect ratios of standard parameters is not yet widely known in the field of Taguchi methodical application (Ujiie et al., 2001; Cardwell, 2015). It requires an adequate understanding of how the standard parameters may be combined with aspect ratios to exploit its full potential and help the turning process to optimize its parameters. These are in terms of the percentage concentration of the nanofluid Al_2O_3, cutting velocity, and feed rate while processing the Inconel X-750 alloy on the turning machine.

To the best of the present authors' knowledge, few studies have analyzed the optimization requirements of turning Inconel alloys because of the poor understanding of the mechanism involved in its application (Kannan and Kannan, 2018; Joshi et al., 2018; Marsh, 2018; Venkatesan et al., 2019a,b,c; Vildirin et al., 2019; Barewar et al., 2021). In adopting the Taguchi method for the turning process, investigators still adopt the parameters in their standard form, where it is not combined or transformed in any manner (Oji and Oke, 2020; Okanminiwei and Oke, 2020; Ajibade et al., 2021). These factors are then experimented upon to determine their levels (Ajibade et al., 2021). The factor-level information then provides the orthogonal array, converted into signal ratios with the help of the factor-level initially defined (Okanminiwei and Oke, 2020). Then the summarized response table is obtained where ranks, delta values, and optimal parametric settings are established (Oji and Oke, 2020). From the previous, the use of these standard parameters are no longer sufficient to meet the requirements of contemporary turning practices in the machine shop because of the following reasons: (1) several materials need to be turned thereby demanding heavy workload and coordinated activities from the process engineer and operators; (2) The complication involved in performance analysis and optimization requires the full usage of performance metrics for the best representation of the system's performance; (3) The use of standard parameters tends to cause performance evaluation to be trapped within local optimal instead of a global optimum.

Consequently, there is an urgency to incorporate the aspect ratios, which helps establish the comparative dimension of one parameter against the other, aiding performance review. Furthermore, existing literature appears to be scanty on the application as the present literature cannot explain the influence of introducing aspect ratios at the factor-level stage of the Taguchi computation to arrive at the ranks, delta values, and the optimal parametric settings of the turning process parameters. This lack of research concerning aspect ratios reveals a huge gap to understand the development of optimal parametric settings and their associated implications from combining the standard parameters and aspect ratios for orthogonal array development, signal-to-noise ratio computations, and finally, the response table establishment. To tackle this research void, an attempt has been made to explain how the aspect ratios of standard parameters are developed, related to the standard parameters in the computation of the optimal parametric settings through the factor-level table to the response table development.

Experimental data from the literature were used using three critical parameters of percentage concentration, cutting velocity, and feed rate from the work of Venkatesan et al. (2019b). The data focuses on the turning process whereby nanofluid Al_2O_3 is introduced into coconut oil as the lubricant in the turning process of Inconel X-750 alloy.

2. LITERATURE REVIEW

This section, literature review, was instituted to demonstrate the present authors' awareness and knowledge of previous studies on the turning operation of Inconel X-750 alloy with applications of nanofluids as coolants before the authors made further exploration. A comprehensive search of scholarly sources was made on the subject's outlines and the present discussion stage to achieve this goal. Consequently, journal articles, thesis, book chapters, and proceedings of conferences were explored. Arising from this investigational effort, diverse perspectives, including different materials used as lubricants, such as Al_2O_3 nanofluids suspended in coconut oils, were discussed.

First, it is argued that conventional fluid in the machining process such as milling, drilling, grinding, and turning is widespread. However, emerging in the machining literature is the use of nanofluids and their hybrids that seek assistance from the minimum quantity lubrication for energy and cost-saving objectives (Venkatesan et al., 2019a). Several reviews have been done regarding this, including Esfe et al. (2020) and Chinchanikar et al. (2021). In the case of Chinchanikar et al. (2021), an effort was made to analyze the influence of concentration, size, thermal conductivity, type, and shape of nanoparticles of the base fluid on the performance of the process. The use of minimum quantity lubrication and the influence of nanofluid on the machining process was investigated. Besides, Yildirim et al. (2019) analyzed the nano-MQL process by adding the nanoparticles of hBN and weighting the outcome against pure-MQL and dry matching while subjecting the Inconel 625 to turning operations. The approach adopted by the authors to verify the proposal is the metallurgical approach using the EDX and SEM analysis. This approach is at variance with the one adopted in the present article, which uses the mathematical methods of Taguchi, Taguchi-Pareto, and Taguchi-ABC. Nevertheless, the work concludes that 0.5 vol.% hBN nanofluids exhibited elevated tool life, low roughness, and low tool wear.

In an interesting article, Junankar et al. (2021) examined the impact of nanofluids prepared with CuO and ZnO and applied under the concept application of the minimum quantity lubrication to turn bearing steel, and the parameters were noted. The selected nanofluids representing the system are the ZnO nanofluid and CuO nanofluid, while combined coconut oil and nanoparticle Al_2O_3 were integrated as the nanofluid in the present work. Besides, no optimization procedure was considered in the work.

Yet, in an additional study, Kumar and Krishna (2020) described how the combined CuO and Al_2O_3 nanofluids with coconut oil were employed in machining AISI 1018 steel. Interestingly, the selection nanofluids contain the one used in the present work (i.e., biodegradable coconut oil with nanoparticle (Al_2O_3), which confirms the satisfactory performance of this nanofluid in turning operations. However, no mathematical analysis seems to have been considered in work; the present study differs from it. It considers three mathematical methods of Taguchi, Taguchi-Pareto, and Taguchi-ABC. Notwithstanding, the principal outcome of their study was that the hybrid nanofluids with CuO and Al_2O_3(50-50) combined lowered the surface roughness by 13.72%.

Furthermore, Yi et al. (2019) claimed novelty in testing the graphene oxide nanofluids while turning Ti-6Al-4V to examine the following responses: surface roughness, cutting temperature, and chip formation. These responses are different from the cutting force, roughness average, and tool wear considered in the present study. Also, while speed and feed rate are common to the study and the present one, the variation is in the nanofluid concentration considered in the present work while cutting depth was analyzed in the study. Apart, while the study tool a metallurgical approach whereby the scanning electron microscope was considered, the present study adopted the mathematical approach of analysis the Taguchi, Taguchi-Pareto, and Taguchi-ABC methods. Besides, neither selection nor optimization was considered in their work, but such concepts focus on the present study. However, the study's main results are that the surface roughness was lowered by 34.34% on the application of graphene oxide.

Besides, Murali, and Varium (2020) persuaded the turning operations community with the results of palm oil and coconut oil-weighted against the dry lubricating condition. Furthermore, they analyzed coconut oil-based nanofluids and palm oil-based nanofluids and used 50:50 combinations of CuO and ZnO in each base fluid. The selected base fluid coincides with the present study to choose coconut oil as the base fluid while the nanoparticles CuO and ZnO are considered different from Al_2O_3 used in the present study. The focus material to turn, AISI 1018, is different from the Inconel X-750 studied in the present article. Besides, the present article is different from the work in those mathematical models of Taguchi, Taguchi-Pareto, and Taguchi-ABC were considered but are absent in the reviewed work. Nonetheless, the study's key conclusion is that the hybrid of CuO and ZuO yielded outstanding results preferred to other groupings.

In another contribution, Rahman et al. (2019) analyzed two nanofluids in a cooling and lubrication aided turning Ti6Al4V. These nanofluids were produced using three nanoparticles of Al_2O_3, $MoS_2$and the rutile TiO_2 added to canola and virgin olive oil nanofluids. The selected nanofluids are different by base oil from the present study. While the current study focused on coconut oil as the base fluid, the reviewed article analyzed canola and virgin olive oil base fluids. Apart, though the nanoparticle Al_2O_3 considered in the present work is one of these examined in the reviewed article, other differences include the omission of mathematical methods either to select or optimize the responses from their system, which is the focus of the present study. Nonetheless, the study concludes that nanofluids prevented tool wear and attraction wear.

In an energy-based study, Khan et al. (2020) developed empirical methods to mimic costs and energy usage to establish system limitations during the turning of AISI 52100 steel with various cooling conditions with nanofluids. The material used as the object of study is different for the study and the present work. While the AISI 52100 steel was analyzed in their study, the focus is on Inconel X-750 for the current work. Besides, the mathematical methods used in the present study are for the selection and optimization of responses, but in the reviewed work, the empirical method developed is for cost and energy consumption purposes. However, the study concludes that the study's outcome is that the models are feasible and could be extended to other metal processing industries.

Additionally, Singh et al. (2018) described the preparation of graphene nanoplatelets suspended in a water-oriented emulsion. The nanofluids turn AISI 304 by applying the minimum quantity lubrication-assisted method. The selected nanofluid in this article, coconut-oriented Al_2O_3 nanoparticles, differs from the water-oriented graphene Nanoplatelets used in the reviewed article. The analysis method, response surface method, is different from the Taguchi, Taguchi-Pareto, and Taguchi-ABC methods used in the present study. Nonetheless, the conclusion from the study is that higher concentrations of graphene nanoplatelets aided in lowering the surface roughness of the machine AISI 304 and the cutting temperature during its machining.

In an innovative study, Ukamanal et al. (2018) persuaded the turning community with experimental work on the synthesis of nanoparticles of TiO_2 using the high energy ball milling procedures and the influence of the nanofluid on the temperature of the chip and the tool while machining the AISI 316 stainless steel subjected to spray impingement cooling situation. The work's selected nanofluid, water-oriented TiO2 is different from the one selected in the present study, coconut-oriented Al_2O_3 nanoplatelets, making the present work novel. Furthermore, the work adopted a metallurgical property analysis technique involving scanning elect microscopy usage and energy dispersive X-ray spectroscopy to understand more details about the AISI 316 stainless steel used in the study. However, the adoption of the Taguchi, Taguchi-Pareto, and Taguchi-ABC methods was not made in work, disclosing the novelty of the present work. Nonetheless, it was revealed that tool temperature coupled with the chip temperature was produced at the lowest levels.

In another article, Joshi et al. (2018) described the influence of diverse situations on surface roughness while turning Inconel 600 samples. The selected nanoparticles, Al_2O_3, are the same as the present study, while the same parent name for the base fluid, vegetable oil, applies to both studies. The specifically based fluid used in this study is coconut oil, which differs from the one used by the authors. Besides, the mathematical computations used in the present work are the Taguchi, Taguchi-Pareto, and Taguchi-ABC methods. However, no mathematical computations were established in the work. Nonetheless, the conclusion from the study is that surface quality becomes superior on the assistance of the minimum quantity lubrication using the nanofluid when weighted against the dry turning condition.

Furthermore, Venkatesan et al. (2019b) concurred with the literature on nanofluids in preference to conventional dry-cut turning operations. They studied the influence of cutting parameters and the Al_2O_3 nanofluid in the coconut oil base fluid on the tool wear, roughness, and force. The nanofluid in this nanoparticle and base fluid contents is the same as used in the present study. However, there is a divergence of tool implementation in the two studies. At the same time, the Taguchi, Taguchi-Pareto, and Taguchi-ABC methods were deployed in the present study, and no mathematical analysis was conducted in the reviewed work. Wang et al. (2020) conducted a review focusing on the interface of nanofluids and minimum quantity lubrication in the turning process. Venkatesan et al. (2018) examined tool wear in dry turning experiments regarding Inconel X-750 and Waspaloy and studied flank and nose wear changes. The results were that wear rate was elevated in machining wasp log when weighted against Inconel X-750 material.

Junankar et al. (2021) argued that sustainable machining practices and their improvement should be the responsibility of machining industries. For the present purpose, sustainable turning is a green practice that minimizes waste, and the minimum quantity lubrication becomes relevant in this context. Besides, sustainable turning deals with turning hard-to-machine metals such as the Inconel X-750 considered in this article by adopting economically-sensible procedures, reducing the negative impacts of turning the Inconel X-750 material on the environment through proper disposal and revise of waste lubricants. Sustainable turning extends this definition to the conservation of energy used for turning (i.e., electricity) and natural resources. The global benefits of sustainable turning include improving employees' characteristics (welfare and heat conditions while turning metals), the community, and turning Inconel X-750 safety. Furthermore, Junakar et al. (2021) asserted that such practices call for adopting minimum quantity lubrication (MQL) procedure with nanofluid servicing and the working fluid to ensure eco-friendly metal cutting operations. Consequently, adopting the MQL concept as a procedure to function with the nanofluid (coconut-based Al_2O_3 nanoparticles) has justification for turning the Inconel X-750 difficult-to-machine materials, as demonstrated by Venkatesan et al. (2019b).

Junankar et al. (2021) reviewed the improvement and influence of the turning process, including turning alongside using hybrid nanofluids. The coverage of the review entails various approaches to synthesis and characterization that entail lubrication pressure, nanoparticle size, mode of supply, and base fluid. The authors concluded that hybrid nanofluid turning offers a more appealing surface quality of products them other cooling situations. Nonetheless, the optimization aspect of drilling was not captured in work. In another contribution, Purohit et al. (2021) assessed the effect of Cu nanofluid on bearing steel turning operation by deploying an L9 orthogonal array to conduct the experiments. The authors used the grey relational analysis to establish the optimal situation as a multi-objective optimization method. The most important conclusion is that Cu nanofluid having the minimum quantity lubrication had the most substantial cooling influence weighed against the vegetable cutting fluid. The selected response of surface roughness is the same as the one used in the present work. However, other responses such as the force in the direction and the wear were not considered. Furthermore, the economic aspects of the work were not accounted for.

In another work, Singh and Chatha (2021) examined the tribological attributes of Al_2O_3 nanoparticles, an additive to vegetable oil, to turn with an assisted minimum quantity lubrication scheme. The selected nanoparticle, Al_2O_3, is the same as chosen in the present study. However, the bare fluid is different from coconut oil established in the present study weighted against vegetable oil in the reviewed paper. None was used in their work concerning mathematical methods, but the current paper considers the present worth method and the Taguchi method. Nonetheless, the conclusion is that 1% concentration of nanoparticles is preferred to the 3% concentration nanoparticle. However, the 3% minimum quantity nanofluid lubrication yielded excellent accomplishment regarding tool wear.

Furthermore, Wilidrim (2020) analyzed the nano additive-oriented cutting fluid and liquid nitrogen-oriented cryogenic cooling while turning the hardened AISI 420. The selected nanofluid, which is graphene nanoplatelets (GnP) mixed with cutting oil, is different from the Al_2O_3 nanoparticles in coconut oil bare fluid considered in the present work. However, economic models are absent in the work. Nonetheless, the work concludes that cryogenic cooling gained preference in reducing the temperature at the interaction of the tool and chips, an extension of tool life, reduction of tool wear, and excellent chip morphology. However, nanofluid had an edge in attaining an attractive roughness average and surface topography.

In another article, Das et al. (2019) analyzed the cutting performance to enhance the machinability while turning the high-strength-low alloy AISI 4340 steel under varying contents of nanofluids by the assisted minimum quantity lubrication method. The selected nanoparticles of ZnO, Fe_2O_3, Al_2O_3 nanoparticle is the same as the current paper. However, deionized water's base fluid is different from the present paper, coconut oil. Nonetheless, the work concludes that CuO has the best performance and/then ZnO, but the Al_2O_3 revealed the poorest performance as the nanofluid. Furthermore, Sarikaya et al. (2021) analyzed the performance of whisker-fortified ceramic cutting tools using nano-scaled solid lubricants dissolved in MQL to turn co-oriented Haynes 25 alloy. The selected nanofluid in the present article is different from those selected in the article, i.e., coconut-oriented Al_2O_3 against hBN oriented nanofluid MQL, MoS2-oriented nanofluid MQL, and the graphite-oriented nanofluid MQL. Besides, there is no mathematical analysis conducted on the economics of the turning process, which is considered in the present work.

Nonetheless, the conclusion from the study is showcased the positive parts of each aspect. For instance, the minimum surface roughness was achieved using the graphite-oriented nanofluid MQL. In contrast, the hBN oriented nanofluid MQL exceeded in reducing the notch wear and the values of the nose wear.

Yet, in another article, Yi et al. (2020) examined the performance of a graphene-oriented cutting fluid while machining Ti-6A-4V and varying the contents of graphene oxide in the nanofluid. The selected material in the present work, Inconel X-750, is different from that used in Ti-6A-4V. Also, the nanofluid used in the present work, coconut-oriented nanofluid, is different from the graphene-based nanofluid used. Additionally, the mathematical analysis concerns the economic aspects aided by the Taguchi method. But such an analysis is absent in work, making it a novel approach to the problem of machining with nanofluids. Notwithstanding, the conclusion from the study is that turning the Ti-6AL-4V material under the application of graphene-oriented nanofluids yielded significantly less vibration than base fluids.

Furthermore, Barewar et al. (2021) address the sustainable machining area by introducing a new Ag coated ZnO nanoparticle in ethylene glycol base fluid while seeking the assistance of the minimum quantity lubrication method. The selected nanofluids in the present work, coconut oil-oriented Al_2O_3, differ from the Ag/ZnO nanoparticle suspended in the glycol base used in the reviewed work. Also, no mathematical treatment of the Taguchi optimization aspect of machining was conducted but taken as an essential research route in the present study. Nonetheless, the study's key conclusion is that the cutting environment impacted the roughness average and the cutting temperature with 24.52% and 44.74%, respectively.

Besides, Elsheikh et al. (2021) sought the assistance of the minimum quantity lubrication method using the Al_2O_3, and CuO added to rice bran vegetable oil while machining AISI 4340 alloy. The selected nanofluids in the current work, coconut oil-oriented Al_2O_3, differ in the base fluid, rice bran vegetable oil in the reviewed work. However, one of the nanoparticles, Al_2O_3, is the same in the two cases. While particle swarm optimization is part of a hybrid mathematical model used in the reviewed article, it was not directed at the Taguchi optimization aspect, which is the primary concern of the present article.

Furthermore, Sirin et al. (2021) examined the effect of diverse cutting situations on surface roughness, flank wear and its mechanism, utmost cutting temperature, 2D-surface topography, micro-hardness, and cutting force during the milling of alloy X-750 using Sialon ceramic tools. The surface roughness is common to both the current article and the reviewed work for the selected responses. Also, the work material appears to be similar. However, there is no mathematical treatment on the Taguchi optimization aspect of the work, but such an assignment is the pursuit of the present study.

Moreover, Padmini et al. (2016) studied the performance of nanofluids with vegetable oil as the base oil. The workpieces are AISI1040 steel, while the minimum quality lubrication was sought. The selected base oil, i.e., in the current paper, coconut oil, is the same as one of those used by the author. Nevertheless, the current article differs from the current article in its treatment of the Taguchi, Taguchi-Pareto, and Taguchi-ABC methods. However, no mathematical treatments were considered in the reviewed work. Therefore, the present article diverges from the literature in model usage. Besides, the work material in the current work is the Inconel X750, which differs from the AISI 1040 steel used in the reviewed work.

Aside, Chetan (2016) machined nickel-based alloy under an assisted minimum quantity lubrication scheme while using water-based nanofluid with the nanoparticles as Al_2O_3 and a colloidal solution containing silver. While Al_2O_3 serves as a common ground in both studies, the consideration of mathematical models of Taguchi, Taguchi-Pareto, and Taguchi-ABC are missing in their work. Nonetheless, it was concluded that the nanofluids lowered the cutting force, curling chips, and tool wear while machining nickel-based alloy.

Also, Sharma et al. (2015) examined the influence of carbon Nanotube usage on turning the AISI D2 steel with assistance from the minimum quantity lubrication scheme. The selected work material, AISI D2 steel, differs from the Inconel X-750, the work material for the present study. In another contribution, Tanmaisaigeetha et al. (2021) examined the machining of AISI 4340 material under various nanoparticles of graphene and combined graphene and copper insoluble oil. The differences between the work and the current work lie in the work material used since Inconel X-750 is used in the present work while AISI 4340 material was used in the reviewed work. Also, mathematical models of Taguchi, Taguchi-Pareto, and Taguchi-ABC were used in the present article and not deployed to solve any problem in the reviewed article. Nonetheless, the conclusion from the article is that the lowest flank wear was experienced while the graphene nanofluid and hybrid nanofluid were used.

3. METHODS

3.1. Taguchi method

A procedural method is recommended to use the Taguchi method from the combined optimization and selection approach. Several process methods have been established to achieve this goal in recent past years. A few prominent methods are the Taguchi method's variants that involve economic models such as the interest rate factor. Other versions are the Taguchi-Pareto and Taguchi-ABC approaches (Ajibade et al., 2016; Okanminiwei and Oke, 2020; Ajibade et al., 2021). The Taguchi-Pareto builds on the Pareto scheme to prioritize the optimized factors simultaneously (Ajibade et al., 2016; Okanminiwei and Oke, 2020; Ajibade et al., 2021). While the Taguchi-ABC follows a similar approach to prioritization and optimization like the Taguchi-Pareto, it deviates from it by separating the factors into three sections based on the ABC classification scheme instead of only one instituted by the Taguchi-Pareto method (Ajibade et al., 2016; Okanminiwei and Oke, 2020; Ajibade et al., 2021). Although the variants of Taguchi-Pareto and Taguchi-ABC will be discussed later in the method's section, only the Taguchi method, whose standard characteristics are extremely the same, is discussed. At its core, five process steps could be established, which must be conducted following the other, for the implementation of the Taguchi method when analyzing the experimental results of the turning operation while engaging the material subtraction process for the Inconel X-750 alloy on using the Al_2O_3 suspended in nanofluid which is itself embedded in the coconut oil. The first step comprises the establishment of the factors and levels. While implementing this, the aspect ratios of all the parameters used are determined and introduced to complement the standard parameters while maintaining only five parameters at a time given the constraints of selecting an orthogonal array from the Minitab 18 software. This generates a factor-level table for all alternatives as alternative formulations are made by first considering the primary parameters and then additional parameters of the aspect ratio perspective. The total number of parameters formulated does not exceed five. This limitation is imposed on the formulation to avoid formulations that fail to yield any feasible orthogonal matrix specification when the levels are developed. The second step is to determine the orthogonal array matrix for the formulated factor-level combination. The Minitab 18 (2000) may often be a useful resource for the orthogonal array selection as a pre-examined specification has been programmed into the software's Taguchi design mode of operation. Only the number of factors and the convenient number of specified levels are specified. Thus, in this step, the specification of the orthogonal array is agreed upon with the details of the matrix specified on the spread-sheet. The third step comprises computing the signal-to-noise ratios for the problem. To attain this, the researcher needs to decide what criterion best fits the system by choosing among three criteria: smaller-the-better, nominal-the-best, and larger-the-better. Each criterion has a mathematical representation with which the factors are subjected if assumed to follow a particular criterion choice. For example, if it is found on examining all the factors that by decreasing the measures, in turn, results in decreases in the outcome desired and it is acceptable, then the smaller-the-better criterion is chosen, represented as STB (Oji and Oke, 2020),

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

where y_i is the value of the parameter at each count and n is the total number of parameters.

Equation (1) implementation starts with deciding what criterion represents the problem correctly, and the smaller, the better the current choice. Then each representative value is taken from the factor-level table and squared along the row. This represents operation for only an experimental trial out of the several experimental trials possible. The squared values are then summed up for all the factors in the experimental trial of concern. Furthermore, the summed values are divided by n, representing the number of factors considered. Then logarithm operation is applied to the outcome. Finally, the resulting value is multiplied by minus 10 to arrive at the signal-to-noise ratio.

However, on finding out that all the factors increasing the measures in turn, the results are increases in the outcomes, and that this is desirable by the system evaluators, then the larger-the-better (LTB) criterion is chosen, represented as (Oji and Oke, 2020):

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

where n and yi are as previously defined for the STB criterion.

To implement Equation (2), the process engineer commences with deciding what criterion rightly represents the problem, and the-larger-the-better is the preferred choice in this situation. Then, from the factor-level table, the process engineer takes each representative value, and these values are squared along the row. This operation should be borne in mind for only an experimental trial out of the several possible experimental trials. The squared values are then converted into reciprocals before being summed up for all the factors in the experimental trial of concern. Furthermore, the summed values are divided by n, representing the number of factors considered. Then logarithm operation is applied to the outcome. Finally, the resulting value is multiplied by minus 10 to arrive at the signal-to-noise ratio.

On the other hand, a situation may be reached such that either increasing the factor or reducing it does not bring about any changes in the output, then the nominal-the-best (NTB) criterion of the signal-to-noise ratios is chosen, represented as (Oji and Oke, 2020):

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

where y_i represents the attribute indicating the performance of the i^{th} value.

n is the number attached to the experimental trial.

s^2 indicates the variance observable within the data.

The implementation of Equation (3) follows the approach adopted for the smaller-the-better criterion in Equation (1) but with an addition that the variance of the data is calculated and used to divide the value carried forward from the implementation of Equation (1).

Furthermore, a situation may arise such that a factor is preferred to be treated by a criterion. In contrast, others are treated by other criterion/criteria such that mixed criteria are used to treat signal-to-noise factors. Different criteria are introduced, and the overall signal-to-noise ratios are further processed to develop optimal parametric settings and ranks. The fourth step consists of deriving the response table from the computations of the signal-to-noise ratios. This involves tracking particular values of parameter signal-to-noise ratios by level type and averaging these values to obtain a representative value under the response table representation. But another part of this step is to introduce the delta values (DT), represented mathematically as follows:

DT = Highest value of averaged signal-to-noise ratio - lowest value of averaged signal-to-noise ratio for each parameter (4)

Yet another component of this step is the development of ranks, which places the highest delta values as the first other are placed relative to the first position by values.

3.2. Taguchi-Pareto method

A preamble on the Taguchi-Pareto method has been given in the previous sub-section that explains the steps to implementing the Taguchi method for the turning operation involving Inconel X750 alloy while being turned with nanofluids. Thus, since the procedures for the methods of Taguchi and Taguchi-Pareto are a similar and overlapped, reference to those steps in the Taguchi method, which will be useful in this section, is made. But to use the Taguchi-Pareto method from a concurrent optimization and prioritization perspective, the structured process followed commenced with the first step. The first step comprises the first three steps of the Taguchi method, namely establishment of factors and levels, definition of orthogonal array matrix, and the determination of the signal to noise ratios based on the individual criterion of smaller-the-better, nominal-the-best, and the larger-the-better. The second step entails rearranging the experimental trials generated according to the magnitude of the signal-to-noise ratios. Here, descending order of magnitude for the signal-to-noise ratios is expected. In the course of this, obtain an additional column for the percentages of each signal-to-noise ratio to the total signal-to-noise ratio values. Another component of this step is to obtain a cumulative percentage value for the arranged signal-to-noise ratios. Yet, another step component is to establish an 80% or near 80% cut-off mark for the cumulative percentage of the signal-to-noise ratios. The rule is (Oji and Oke, 2020):

Retain the experimental trials with their signal-to-noise ratios

if the SNR % $\geq$ 80%

Else cut off the experimental trials (5)

The third step consists of developing the response table as indicated in the fourth step of the Taguchi method. Here only 80% of the experimental trials by percentage cumulative signal-to-noise ratio is accounted for while the other 20% is discarded. Another component of the third step is evaluating the delta values according to Equation (4) previously defined in the stepwise definition for the Taguchi method.

Finally, Equation (6) indicates how the Taguchi-Pareto method is computed by its objective function (Ajibade et al., 2019; Oji and Oke, 2020):

$$S/N = -10\log_{10}(1/n\sum_{i=1}^{n} P_{80-20} y_i^2) \quad (6)$$

where y_i may be assessed using the lower-the-better criterion. If the higher, the better is desired, the y_i^2 becomes reciprocal, n shows the trials. At the same time, the S/N represents the signal-to-noise proportion for the system being evaluated, but the P_{80-20} may be obtained as earlier indicated. Furthermore, by following Equation (1) steps but with an amendment, Equation (6) is implemented. The amendment restricts the computation of the signal-to-noise ratios to the biggest problems that often matter roughly 80% of the situation.

3.3. Taguchi-ABC method

Based on the pre-amble given on the Taguchi-ABC method as mentioned in the Taguchi method, the steps to implement the Taguchi-ABC are elaborated here. However, using the Taguchi-ABC is another route to obtaining a concurrent optimization and prioritization perspective. Three segmentation, A, B, and C, are made instead of only one representing the Taguchi Pareto alternative. In the Taguchi-ABC, all three sections are essential, with A having the most importance, B exhibiting middle importance, and C demonstrating the least importance. The first step is the same as the first step of the Taguchi-Pareto method. The second step comprises rearranging the experimental trials generated according to the magnitude of the signal-to-noise ratio. Descending order of magnitude is perfumed. While obtaining this, an additional column is created for the percentages of each signal to noise ratio to the total signal to noise ratio values. Then, as an additional component of this step, a cumulative percentage for the arranged signal-to-noise ratios is obtained. Furthermore, an additional component of this method is to establish three cut off as C (including a 69% or near 69% cut off the mark), B (including a range of 70% to 79% cut off the mark), and A (including an 80% or near 80% cut off the mark). The mathematical expression for this method is as follows (Oji and Oke, 2020):

Retain the experimental trials with their signal-to-noise ratios if the SNR% is between 80%-100% as A, 70% - 79% as B and 1% - 69% as C (7)

The third step consists of developing the response table, as shown in the fourth step of the Taguchi method. Here, three response tables, each for sections A, B, and C, are created then the optimal parametric settings and ranks are determined.

Finally, Equation (8) indicates how the Taguchi-ABC method is computed by its objective function (Ajibade et al., 2019; Oji and Oke, 2020):

$$S/N = -10\log_{10}(1/n(ABC)\sum_{i=1}^{n} y_i^2) \quad (8)$$

where y_i may be assessed using the lower-the-better criterion. If the higher, the better is desired, the y_i^2 becomes reciprocal, n shows the trials. At the same time, the S/N represents the signal-to-noise proportion for the system being evaluated, but the *ABC* may be obtained as earlier indicated. Besides, by following Equation (1) steps but with an amendment, Equation (8) is obtained. The amendment restricts the computation of the signal-to-noise ratios to a class of problems, namely A, B, and C. A is the most critical group, B is next in importance, while C is the least important problem.

3.4. Determination of the factor level table

Since the factors considered in the ratios have not been previously specified in the literature, the procedure for determining the factors and levels table involves steps appended to those used in the classical method of factor-level table determination. To understand this approach, the following steps are recommended. The first step consists of determining the number of factors in the

Table 1: The results of the experimental trials, Venkatesan et al. (2019b)

Level	Percentage Concentration (%)	Cutting Velocity (m/mm)	Feed Rate (mm/rev)
1	0.25	40	0.14
2	0.50	60	0.17
3	1.00	100	0.20

standard form. For example, from the experimental data adopted from Venkatesan et al. (2019b), three factors are classified as the primary factors, including the percentage of concentration cutting velocity and feed rate. In the course of this step, if C, V, and F are used to represent these factors, respectively, then these factors, which are three, qualify for inclusion in the factor-level table. Another component of this step is to consider the aspect ratios of these factors one to another. As there are three factors, C, V, and F; taking the first factor C, aspect ratios could be developed from its relation to V and as F C/V and C/F respectively. A feasible orthogonal array may be formed since the work is constrained to roughly five factors. The five factors formed are C, V, F, C/V, and C/F and are grouped as the first formulation alternative. Yet, in the course of this step, it was noted that several alternatives could be formulated.

Consider transforming the aspect ratios C/V and C/F formed in alternative 1 to their reciprocal as V/C and F/C. These aspect ratios could be joined to the other three primary factors of C, V, F, V/C, and F/C and would be termed alternative formulation 2. Furthermore, there are twelve possible alternative formulations to the problem by rationing the three primary factors and adding aspect ratios such as V/F, I/V, and V/C. Hence, a comprehensive test involving all the alternatives regarding response tables, ranks, delta values, and optimal parametric settings is desired.

3.5. Application of the method

The experimental results utilized in this research were extracted from Venkatesan et al. (2019b), as shown in Table 1.

The results in Table 1 are the inputs of turning operations carried out on the lathe machine by Venkatesan et al. (2019b). Traditionally, while implementing the Taguchi DOE for designing experiments on turning a nickel-chromium alloy, the literature specified the need to establish the input parameters. These are the % concentrations, cutting velocity, and feed rate for the Inconel X-750 alloy utilized in this work, as declared by Venkatesan et al. (2019b). The levels under which the experiments are to be analyzed are also needed, and these are levels 1, 2, and 3 in the present study. To obtain Table 1, Venkatesan et al. (2019b) first obtained the nanofluid for experiments, obtained the calibrated values of the turning machine, and the manufacturer's designed feed rates of the turning machine. At first, based on experience, the authors set the commencement point of analysis for the percentage concentration at 0.25%. They set the cutting velocity at 40 mm/min while the feed rate was set at 0.14 mm/rev according to the manufacturer's graduation of the turning machine. At this stage, the turning of the material was pursued by providing a specified number of samples. Afterward, the percentage concentration was adjusted to 0.50% and the next grade of cutting velocity, 60 mm/min set for the turning of the material. Also, the machined-fixed graduation of 0.17 mm/rev for the feed rate was made, and samples turned. Later, the percentage concentration of the nanofluid was adjusted to 1%, cutting velocity to 100 mm/min, and feed rate to 0.20 mm/rev, and samples were produced.

The outcome of this exercise is the development of Table 1. Interestingly, Table 1 was created to establish the orthogonal array for the chosen factors as these alloys are the building blocks to obtaining fewer experiments using Taguchi's experimental design framework. Orthogonal arrays are entry-containing tables with preset integers, often greater than 1, for a fair representation of the occurrence of a factor-level combination arrangement. Table 1 consists of factors and levels whereby each factor is specified at defined thresholds, often decided by the decision-maker or are constrained by the calibration of the equipment for the analysis. In particular, Table 1 was extracted from the literature in the work of Venkatesan et al. (2019b).

In this work, the key concern is to establish the most important factors that influence the outputs of the turning operation for the Inconel X-750 alloy. Besides, it is compelling to establish what level of each of the stated three parameters of % concentration, cutting velocity, and feed rate significantly influence the response for the turning operation. The optimum performance desired in the present work would be obtained in this context. Table 1 principally contains elements that describe the levels, % concentration of nano-fluids, cutting velocity, and feed rate. A detailed explanation of each of these elements is thus given, starting with levels. The term levels were applied in the Taguchi design of experiments (DOE) implemented in Venkatesan et al. (2019b). This shows the association of the design (response) and parameters in any cubic, linear or quadratic, or other applied forms.

The level also shows the low and high positions of each parameter tested in Venkatesan et al. (2019b). The authors determined the number of levels, as three parameters are considered in this work, namely % concentration, cutting velocity, and feed rate. The authors set the level for the parameters for the various percentage concentrations initiated. Others are the diverse cutting velocity of the Inconel X-750 alloy utilized on the lathe with multi-axis features. The authors also set the level for the parameters of the diverse feed rate concerning the Inconel X-750 alloy on the turning operation with a lathe machine. Three levels were used for all the parameters (factors). Next is the description of what factors are, in general, factors are otherwise referred to as parameters. In the turning operation of Inconel X-750 alloy, parameters are the

Table 2: Standard and aspect ratios for turning parameters and levels

Level	C	V	F	C/V	F/V
1	0.25	40	0.14	0.00625	0.00350
2	0.5	60	0.17	0.00833	0.00283
3	1.0	100	0.20	0.01000	0.01000

variables such as percentage concentration, cutting velocity, and feed rate subjected to control by the authors during the experiments. While they represent the key attributes of the turning process, they are independent in that they are effective predictors of the outputs.

The turning experiment intends to choose the parameter levels such that a reduced influence of the noise factors on the response is observed. In the experiment whose results are utilized in this work, the material used is the Inconel X-750 alloy. But the attraction to this nickel-chromium alloy is excellent properties from room temperatures to cryogenic temperatures. The Inconel X-750 alloy is hardenable through precipitation that involves the introduction of titanium to aluminum. The attractive attribute of the nickel alloy involves its elevated creep-rupture and raised temperatures to roughly 700°C (130.0°F) gives much credit to the usage of Inconel X-750 alloy in engineering processes.

Special Metals (2014) described the composition of X-750 alloy as containing a maximum of 1% of cobalt and manganese a maximum of 0.5% of silicon and copper. Others are maximum values of 0.08% 0.01% for carbon and Sulphur, respectively. Furthermore, nickel (plus cobalt) has a minimum of 70% in the chemical composition of Inconel X-750 alloy. The ranges (14.0–17.0) %, (5.0-9.0) %, (2.25-2.75) %, (0.4-1.00) % and (0.70-1.20) % for chromium, iron, titanium, aluminum and niobium (plus tantalum), respectively. Furthermore, Taguchi, which focuses on the aspect ratios involving seven factors with forty-eight alternatives, was used. In addition, Taguchi-Pareto and Taguchi – ABC data optimization methods are introduced to the input parameters to yield the desired outputs.

4. RESULTS AND DISCUSSIONS

4.1. Problem addressed

The establishment of a viable turning operation performance measure and optimization analysis while turning the Inconel X-750 alloy using nanofluid lubricants. It requires a deep understanding of the interactions among the key factors. It needs their levels, evaluation of their signal-to-noise ratios, a summary of their responses, and the optimal parametric setting while using the Taguchi methods in varied settings as classical Taguchi method, Taguchi-Pareto, and Taguchi-ABC methods. Historically and presently, several turning experimental analyses omits efforts to include the aspect ratios of the key parameters for potential enhancement in the optimal parametric setting and reflection of the true ranks of the parameters during the selection process and resource conservation by distributing turning resources to parameters according to the importance of the parameters. The limited factor information utilized about the levels by the orthogonal matrix for the computation of signal-to-noise ratios is no longer detailed enough or representative considering the form of turning operations prevailing today in the manufacturing domain and the turning industry practices, which constantly involves innovative performance measures. Continuing the current Taguchi optimization practices that omit a superior understanding and tackling of factor choice and inclusion of aspect ratios of factors may result in substantial uncertainty and error when developing turning operations' optimization values for parameters.

4.2. Taguchi approach of optimization

The Taguchi method of optimization in the present study is analyzed further about its aspect ratios by Taguchi, Taguchi-Pareto, Taguchi-ABC approaches. In forming the aspect ratios, the original standard parameters in Table 1 are therefore used to compare each other following the aspect ratio standard formation, analyzed in Table 2. Venkatesan et al. (2019b) state that the experimental parameters are three factors and three levels. These are the percentage concentration of cutting (%), cutting velocity (m/min), and feed rate (mm/rev). In work by Venkatesan et al. (2019b), the conventional approach to evaluating with the Taguchi method was adopted, as shown in Tables 2, 3, and 4. The approach is based on defining the parameters, establishing their signal-to-noise ratios, and determining their ranks using the standard parameters only. However, this approach is abandoned in this work, and a new approach is implemented. The new approach introduces aspect ratios to substitute for the standard parameters based on the success of aspect ratio application in the field of formability engineering, where aspect ratios assist in obtaining better performance results. In this context, it is understood that although percentage concentration, cutting velocity, and feed rate are the primary parameters, ratios of each of these parameters may be formed and tested using the procedure of signal-to-noise ratio formulation and the development of ranks. This is called the Taguchi approach using the aspect ratios, which is proposed for the first time in literature in this work. By using the key at the base of Table 2, for the three parameters studied C, V, and F, the aspect ratios could be formed by dividing each of C, V, and F by V. This gives C/V, V/V, and F/V and is summarized as only two factors, i.e., C/V and F/V. But these two factors are limited in testing. Therefore, the original parameters C, V, and F are added to give five factors as C/V, F/V, C, V, and F. These factors are used in the Taguchi method. The factors passed through a signal-to-noise formulation and the development of ranks to obtain the best parameters.

Table 2 is platform for analysis for the Taguchi method. The first column represents the levels classified into three, i.e., 1, 2, and 3. The second, third, and fourth columns are nanofluid concentration, cutting velocity, and the feed rate. However, as an extension of Table 1, two additional columns, fifth and sixth, are created. The fifth column is the first aspect ratio, which divides the second column by the third column, while the sixth column is the second aspect ratio that divides the fourth column by the third column. Notice that the aspect ratios, i.e., C/V and F/V are the ratios of concentration to the cutting velocity for the C/V. In contrast, the feed rate ratio to the cutting velocity is demonstrated in the formulation of the F/V aspect ratio.

Next is the determination of the orthogonal array from the Minitab Version 18 (2020). The obtained orthogonal matrix is L27, where the design summary is specified along three dimensions of Taguchi array as L27(3^5), factors as five, and runs as twenty-seven. The obtained orthogonal array is translated into actual values and computed signal-to-noise ratios. In determining the signal-to-noise ratios, the criterion of smaller the better is used for percentage concentration because the smaller values of this factor are desired. As previously defined in the methodology section, the expression for smaller the better is used. The smaller the better criterion is used for the cutting velocity and the feed rate, and the equation of the smaller the better criterion used in both cases. Furthermore, the smaller the better criterion was used for both C/V and F/V ratios, while the results are reported in Table 3.

The first column of Table 3 is the experimental trials of twenty-seven runs obtained from the Minitab Version 18 (2020) software. The second to the sixth column reveals the orthogonal array by levels of the factors.

The seventh to the eleventh column is the translated orthogonal array from Table 2. For instance, on the seventh column and the first row, the 0.25 indicated is obtained from the intersection of level one and factor C in Table 2. The same procedure obtains all other entries under the translated orthogonal array matrix. The smaller, the better signal to noise criterion is used for all the factors, and the signal to noise value is obtained as -25.05172 for experimental trial 1. The same procedure is used to get the signal to response ratios for the other twenty-six experimental trials.

Table 4 shows the response table evaluation for the joint standard and aspect ratios of the turning process. The ranks of C, V, and F were compared when treated alone as three factors for the computations of the response table with the case where it is treated jointly with aspect ratios. It was decided to find out if introducing aspect ratios C/V and F/V in the computation of the response table will influence ranks or not. It is interesting to note that the ranks changed by introducing these aspect ratios. When C, V, and F are computed under the signal-to-noise ratio procedure, the positions of 1^{st}, 2^{nd}, and 3^{rd} were respectively obtained for these factors. Here, the delta values of 7.95774, 0.00137, and 0.00064 were obtained for percentage concentration, cutting velocity, and feed rate, respectively, with the corresponding optimal parametric setting as $C_1V_1F_2$. However, on introducing C/V and F/V into the computation of the signal-to-noise ratio and then responses, the positions of C, V, and F changed to 2^{nd}, $1^{st,}$ and 4^{th}, respectively. The interpretation of the results is that percentage concentration gives the best effect on the turning operation of Inconel X-750 alloy using the standard factors.

In contrast, the feed rate gives the worst effect on the turning of the alloy. These viewpoints are opposed when the joint standard and aspect ratios are considered. In this situation, the interpretation is that cutting velocity gives the best effect on the turning operation of the Inconel X-750 alloy, while the feed rate gives the worst effect. Given these viewpoints, the researcher recommends adopting the results where the standard factors are joined to the aspect ratios. Cutting velocity should be considered as the worst in their effects on the turning operation of Inconel X-750 alloy. In Table 4, the summaries of the entries of Table 3 are given. For instance, the values of ratios mapped to orthogonal index 1 are averaged. It means that SNR values from experimental trial 2 to experimental trial 9 averaged to yield -28.87850.

Similarly, all other entries in Table 4 are obtained. The delta values are obtained by looking at each column containing the signal-to-noise ratios and subtracting the smallest from the highest. The highest delta value is given the 1^{st} position, and the rest are ranked accordingly. Thus, in Tale 4, cutting velocity is ranked 1^{st}, percentage concentration is ranked 2^{nd}, C/V is ranked 3^{rd}, F is ranked $4^{th,}$ and F/V is ranked 5^{th}. The optimum parametric setting is then obtained from the highest SN ratio as $C_1V_1F_2C/V_1F/V_1$. Next, the idea of Taguchi-Pareto is considered.

4.3. Taguchi-Pareto approach of optimization

The Pareto principle applies the 80-20 rule, which was used in the present work. The results of the Taguchi-Pareto application are also shown in Table 4. A cumulative signal to noise ratio was obtained and later transformed to a cumulative percentage signal to noise ratio. The analysis observed that the first twenty-two experimental trials after the rearrangement of the signal-to-noise ratios met the 80% cut-off point. Thus, experimental trials twenty-three to twenty-seven were discarded since they may not be influential on the turning performance.

Compared with the Taguchi method, the ranks obtained through the Taguchi-Pareto method are surprisingly the same as those obtained from the Taguchi method. Here, the cutting velocity, percentage concentration, the aspect ratio of percentage concentration to cutting velocity hold the first, second, third, fourth, and fifth positions, respectively. This means that the aspect ratio has the same effects of the parameters on the system's performance is felt in both cases. The optimal parametric setting of the Taguchi-Pareto method is $C_3V_1F_2C/V_1F/V_3$. This means one percent concentration of nano-fluid is optimal with the following optimal values of other parameters; 40m/min of cutting velocity, 0.17mm/rev of feed rate, 0.00625%min/m of the aspect ratio of percentage concentration to the cutting velocity, and 0.01mm. min/rev. m of the aspect ratio of feed rate to the cutting velocity.

Consequently, from the analysis, the following facts are revealed:

Table 3: Signal to noise ratio computation from orthogonal arrays

Exp.	Orthogonal array					Translated orthogonal array					SNR	SNR	SNR	SNR
	C	V	F	C/V	F/V	C	V	F	C/V	F/V				
1	1	1	1	1	1	0.25	40	0.14	0.00625	0.00350	-25.05172	-25.05172	-25.05172	-25.05172
2	1	1	1	1	2	0.25	40	0.14	0.00625	0.00283	-25.05172	-25.05172	-25.05172	-25.05172
3	1	1	1	1	3	0.25	40	0.14	0.00625	0.00200	-25.05172	-25.05172	-25.05172	-25.05172
4	1	2	2	2	1	0.25	60	0.17	0.00833	0.00350	-28.57344	-28.57344	-28.57344	-28.57344
5	1	2	2	2	2	0.25	60	0.17	0.00833	0.00283	-28.57344	-28.57344	-28.57344	-28.57344
6	1	2	2	2	3	0.25	60	0.17	0.00833	0.00200	-28.57344	-28.57344	-28.57344	-28.57344
7	1	3	3	3	1	0.25	100	0.20	0.01000	0.00350	-33.01034	-33.01034	-33.01034	-33.01034
8	1	3	3	3	2	0.25	100	0.20	0.01000	0.00283	-33.01034	-33.01034	-33.01034	-33.01034
9	1	3	3	3	3	0.25	100	0.20	0.01000	0.00200	-33.01034	-33.01034	-33.01034	-33.01034
10	2	1	2	3	1	0.50	40	0.17	0.01000	0.00350	-25.05226	-25.05226	-25.05226	-25.05226
11	2	1	2	3	2	0.50	40	0.17	0.01000	0.00283	-25.05226	-25.05226	-25.05226	-25.05226
12	2	1	2	3	3	0.50	40	0.17	0.01000	0.00200	-25.05226	-25.05226	-25.05226	-25.05226
13	2	2	3	1	1	0.50	60	0.20	0.00625	0.00350	-28.57367	-28.57367	-28.57367	-28.57367
14	2	2	3	1	2	0.50	60	0.20	0.00625	0.00283	-28.57367	-28.57367	-28.57367	-28.57367
15	2	2	3	1	3	0.50	60	0.20	0.00625	0.00200	-28.57367	-28.57367	-28.57367	-28.57367
16	2	3	1	2	1	0.50	100	0.14	0.00833	0.00350	-33.01042	-33.01042	-33.01042	-33.01042
17	2	3	1	2	2	0.50	100	0.14	0.00833	0.00283	-33.01042	-33.01042	-33.01042	-33.01042
18	2	3	1	2	3	0.50	100	0.14	0.00833	0.00200	-33.01042	-33.01042	-33.01042	-33.01042
19	3	1	3	2	1	1.00	40	0.20	0.00833	0.00350	-25.05432	-25.05432	-25.05432	-25.05432
20	3	1	3	2	2	1.00	40	0.20	0.00833	0.00283	-25.05432	-25.05432	-25.05432	-25.05432
21	3	1	3	2	3	1.00	40	0.20	0.00833	0.00200	-25.05432	-25.05432	-25.05432	-25.05432
22	3	2	1	3	1	1.00	60	0.14	0.01000	0.00350	-28.57455	-28.57455	-28.57455	-28.57455
23	3	2	1	3	2	1.00	60	0.14	0.01000	0.00283	-28.57455	-28.57455	-28.57455	-28.57455
24	3	2	1	3	3	1.00	60	0.14	0.01000	0.00200	-28.57455	-28.57455	-28.57455	-28.57455
25	3	3	2	1	1	1.00	100	0.17	0.00625	0.00350	-33.01075	-33.01075	-33.01075	-33.01075
26	3	3	2	1	2	1.00	100	0.17	0.00625	0.00283	-33.01075	-33.01075	-33.01075	-33.01075
27	3	3	2	1	3	1.00	100	0.17	0.00625	0.00200	-33.01075	-33.01075	-33.01075	-33.01075

Table 4: Response table evaluation for the joint standard and aspect ratios of the turning process

	Response analysis of the signal to response ratio (Taguchi only)					Response analysis of the signal to response ratio (Taguchi-Pareto)				
Levels	C	V	F	C/V	F/V	C	V	F	C/V	F/V
1	-28.87850	-25.05280	-28.87890	-28.87870	-28.87905	-28.87850	-25.05280	-28.96590	-26.81270	-28.36259
2	28.87880	28.57390	28.87880	-28.87940	-28.87905	-28.87880	-28.57370	-26.81280	-28.87940	-28.33231
3	-28.87990	-33.01050	-28.87940	-28.87910	-28.87905	-25.93440	-33.01040	-28.87940	-28.96610	-28.33231
Delta	0.00137	7.95774	0.00063	0.00068	1.19736E-08	2.94440	7.95761	2.15301	2.15335	0.03028
Ranks	2	1	4	3	5	2	1	4	3	5

Optimum parametric settings are $C_1V_1F_2C/V_1F/V_1$ Optimum parametric settings are $C_3V_1F_2C/V_1F/V_3$

Table 5a: Response table evaluation for the Taguchi-ABC alternative one aspect ratio of the result analysis (Sections A and B)

	Standard and aspect ratios (Section A)					Standard and aspect ratios (Section B)				
Levels	C	V	F	C/V	F/V	C	V	F	C/V	F/V
1	NIL	NIL	-28.57000	-33.01070	-30.79000	NIL	-25.0543	-33.01000	NIL	-25.05000
2	NIL	-28.57	-33.01000	NIL	-30.79000	-33.0104	NIL	NIL	-28.24000	-29.03000
3	-30.79000	-33.01000	NIL	-28.57460	-30.79000	-25.05430	-33.01040	-25.05000	NIL	-29.03000
Delta	-30.79000	4.44000	4.44000	4.43619	6.77E-09	7.95610	7.95610	7.96000	-28.24000	3.98000
Ranks	5	1	1	1	4	1	1	1	5	4

Standard and aspect ratios (Section A): Optimum parametric settings are $C_3V_2F_1C/V_3F/V_1$

Standard and aspect ratios (Section B): Optimum parametric settings are $C_3V_1F_3C/V_2F/V_1$

Table 5b: Response table evaluation for the Taguchi-ABC alternative one aspect ratio of the result analysis (Section C)

	Standard and aspect ratios (Section C)				
Levels	C	V	F	C/V	F/V
1	-28.88000	-25.05000	-27.04000	-26.81000	-28.88000
2	-27.70000	-28.57000	-26.81000	-29.68000	-28.05000
3	NIL	-33.01000	-30.79000	-29.03000	-28.05000
Delta	1.18000	7.96000	3.98000	2.87000	0.83000
Ranks	4	1	2	3	5

Standard and aspect ratios (Section C): Optimum parametric settings are $C_2V_1F_2C/V_1F/V_2$

Table 6. Aspect ratios formulated for the optimization analysis of the cutting parameters experimental trials

Factors--→ Alternatives	1	2	3	4	5
1	C	V	F	C/V	F/V
2	C	V	F	C/F	V/F
3	C	V	F	V/C	F/C
4	C	V	F	V/C	F/V
5	C	V	F	F/C	F/V
6	C	V	F	C/V	C/F
7	1/C	1/V	1/F	C/V	F/V
8	1/C	1/V	1/F	C/F	V/F
9	1/C	1/V	1/F	V/C	F/C
10	1/C	1/V	1/F	V/C	F/V
11	1/C	1/V	1/F	F/C	F/V
12	1/C	1/V	1/F	C/F	C/F

First, using the aspect ratio as factors along with the direct parameters for evaluating the optimal process parameters for the turning experiment (see Venkatesan et al.’s (2019b) experiments),

1. The optimal parametric setting using the Taguchi method is $C_1V_1F_2C/V_1F/V_1$, implying 0.25% concentration of nanofluid, 40 mm/min of cutting velocity, 0.17 mm/rev of feed rate, 0.00625% min/mm and 0.0035mm/rev.
2. For the Taguchi-Pareto method, the optimal parametric setting is $C_3V_1F_2C/V_1F/V_3$, interpreted as 1% concentration of nanofluid, 40 mm/min of cutting speed, 0.17 mm/rev of feed rate, 0.00625 %min/mm and 0.20 mm/rev.
3. However, for the best group within the Taguchi-ABC group classification, group A of the Taguchi-ABC method, the optimal parametric setting is obtained as $C_3V_2F_1C/V_3F/V_1$, which is interpreted as 1% concentration of nanofluid, 60 mm/min of cutting velocity, 0.14 mm/rev of feed rate, 100%min/mm and 0.0035 min/rev.

Next, selecting the cutting parameters allows establishing what parameter carries the highest weight of importance. From such information, the decision-maker could channel efforts and resources on such parameters for efficient resource distribution and the qualitative advantage of acknowledging a fair-sharing resource distribution method recognized by the labor unions in constant agitations for fairness among workers. Thus, driven by the perceived benefits of the selection process, results on the application of the Taguchi, Taguchi-Pareto, and Taguchi-ABC methods were obtained. For the Taguchi method, the best parameter is V (cutting velocity), the second position is (percentage concentration of the nanofluid), the third position is the aspect ratio C/V (concentration of the nanofluid to the cutting velocity), the fourth position is F (feed rate). In contrast, the last position (fifth) is F/V (aspect ratio of feed rate to cutting velocity).

Interestingly, by considering the results of the Taguchi-Pareto method for the cutting parameter selection method, the same results were obtained as those of the Taguchi method. This means that V, C, C/V, F, and F/V are positioned from first to last positions. There are no differences in applying the two methods as the system operates efficiently to have self-prioritized resources, and the distribution of resources to the parameter was fairly attained. However, the selection results obtained from using the Taguchi-ABC method are entirely at variance from those obtained from the other methods of Taguchi and Taguchi-Pareto. In the present results, classified as A, B, and C, Group A ranks V, F, and C/V as the first position, F/V as the fourth position, and C took the fifth position. This result attached the utmost importance to the aspect ratio C/V, which ordinarily is not being accounted for in the literature. It means that the ratio of C to V yields the best result for the system considering group A. The group is considered the most important of three groups, A, B, and C. Nonetheless, V and F also tie-up with C/V in the result for group A. For group B, the perception of the result is to attach the first position to C, V, and F. In contrast, the fourth position goes to the aspect ratio F/V, and the fifth position goes to the aspect ratio C/V. This result implies that aspect ratios F/V and C/V are as good as the direct parameters of C, V, and F. However, in group C, the results obtained rank V as the best parameter, F as the second position, the aspect ratio C/V as the third position, C as the fourth position, and the aspect ratio F/V as the last position.

Besides, the Taguchi methods have both qualitative and quantitative interpretations and benefits. While the optimal parametric settings describe an essential quantitative interpretation of the results of this study, a notable benefit of the results in the qualitative form is that the adoption of the optimal parametric setting serves as a target with which employees’ performance may be compared. Thus, the decision-maker must not wait until an employee's annual appraisal. However, comparing the target (optimal parametric setting) with the actual performance could be a driver towards performance improvement of employees based on weekly production performance in the machining of the Inconel X-750 work material. Besides, at the implementation of the optimal parametric setting, the minimum percentage concentration of nanofluid to use in production is defined.

Using excess nanofluid quantities is a waste, and defining the optimal quantities saves cost and conserves the nanofluid resource. Also, at optimal parametric setting, the cutting velocity is defined. This is expected to be the optimum cutting velocity. But the cutting action on the difficult-to-machine material, X-750 Inconel material, generates noise. So the extra noise that may have been generated is avoided by using lower cutting velocity. In addition, cutting actions generate heat, and the heating conditions during machining are reduced, making the employees more comfortable at the workplace. The idea is that extra energy for cooling the environment if extra heat had been provided is avoided while turning the Inconel X-750 material. Besides, low heat conditions low cutting velocity implies enhanced safety conditions for the operator at the workshop.

Furthermore, the advantage of the Taguchi method is the minimization of the number of experiments to be considered for the turning process. The added advantage of using the Taguchi-Pareto method is that it can prioritize and at the same time concentrate on a few essential experimental trials. Therefore, the output from the turning system will be enhanced. This same advantage is brought to the turning operation by the Taguchi-ABC method.

4.4. Advantages and disadvantages of the three approaches of the Taguchi method

This study presents a novel discussion related to the process of optimizing the selection of the best parameters for the turning operations of Inconel X750 alloy with nanofluids. It takes full advantage of the results from the three approaches of the Taguchi method, namely the classical Taguchi method, the Taguchi-Pareto method, and the Taguchi-ABC method. However, selecting the wrong parameters for the turning process may have serious penalties, including increased stop-pages to await turning process resources, frequent complaints from work centers on resource deprivation, declining customer service, and delayed delivery times. This translates into wasted energy, money and time, productivity, and profitability losses.

But while taking advantage of the Taguchi method, the process engineer uses the Taguchi experimental design principles to lower cost. Here, the diverse parameters are concurrently optimized while providing sufficient quantitative and qualitative turning operations information by exploiting relatively few experimental trials. Nonetheless, the traditional limitation of the Taguchi method remains unsolved. The results are merely comparative and fail to reveal the specific parameter attributable to the utmost influence on the optimal parametric setting. Furthermore, resources in turning operations are limited and should be judiciously managed. Therefore, in response to this issue, this study established enhancements to the Taguchi method and presented it as the Taguchi-Pareto method. It introduces the idea of the Pareto principle to focus on the big problems instead of the trivial ones using the 80-20 rule.

The process engineer would establish the root causes of problems associated with the important parameters, thus potentially enhancing the results to the utmost level. Nonetheless, the authors are aware that this method provides solutions to issues, a problem that should be tackled in future research. Besides, unique situations exist where turning operations consider three options of the best, following best and worst cases for efficient allocation of resources to parameters. Therefore, this research defines some improvements to the Taguchi method known as the Taguchi-ABC method to respond to this issue. Here, the principle of the ABC classification scheme in inventory is introduced to focus on more critical parameters with details.

Notwithstanding, it is known that the method suffers from more resource (time) requirements than the Taguchi-Pareto method. In summary, it is observed that the selection of the best parameters obtained by the Taguchi-Pareto and Taguchi-ABC methods are better than the Taguchi-method regarding the prioritization of parameters, which is introduced in the earlier methods. This significantly increases the potentials of the turning process for sustainable operations are resources are conserved while focusing on the biggest problems and parameters in the turning process. Besides, the Taguchi-Pareto and Taguchi-ABC methods have substantially enhanced the turning process's optimization objective that fully establishes the requirement and effectiveness of introducing the two methods for the turning operations process parametric selection problem.

5. CONCLUSION

This article proposes an aspect-ratio-based method for the classical Taguchi, Taguchi-Pareto, and Taguchi-ABC methods to evaluate the turning process parameters in non-prioritized and prioritized forms. These were calculated by considering the three parameters of percentage concentration, cutting velocity, feed rate, and ratios in each evaluation alternative. The factor and levels were organized, orthogonal array decided, signal-to-noise ratios evaluated, and summarized as response table. At the same time, the delta values rank for parameters, and their optimal parametric settings were determined. Furthermore, this article has an essential dimension of results: determining the optimal parametric setting for a newly introduced aspect ratio method based on three methods of Taguchi. These are the classical Taguchi method, the Taguchi-Pareto, and the Taguchi-ABC methods. The second aspect is the conclusions drawn from selecting the best parameters. Thus, from the foregoing, the following conclusions are made:

First, using the aspect ratio as factors along with the direct parameters for evaluating the optimal process parameters for the turning experiment (see Venkatesan et al.'s (2019b) experiments),

1. The optimal parametric setting using the Taguchi method is $C_1V_1F_2C/V_1F/V_1$, implying 0.25% concentration of nanofluid, 40 mm/min of cutting velocity, 0.17 mm/rev of feed rate, 0.00625% min/mm and 0.0035mm/rev.
2. For the Taguchi-Pareto method, the optimal parametric setting is $C_3V_1F_2C/V_1F/V_3$, interpreted as 1% concentration of nanofluid, 40 mm/min of cutting speed, 0.17 mm/rev of feed rate, 0.00625 %min/mm and 0.20 mm/rev.
3. However, for the best group within the Taguchi-ABC group classification, group A of the Taguchi-ABC method, the optimal parametric setting is obtained as $C_3V_2F_1C/V_3F/V_1$, which is interpreted as 1% concentration of nanofluid, 60 mm/min of cutting velocity, 0.14 mm/rev of feed rate, 100%min/mm and 0.0035 min/rev.

Next, the following conclusions are valid concerning the results of selecting the best parameters for the Taguchi, Taguchi-Pareto, and Taguchi-ABC methods.

4. The selected best parameter for the Taguchi method is V (cutting velocity), and the worst parameter is the aspect ratio F/V (ratio of feed rate to cutting velocity).
5. Furthermore, for the Taguchi-Pareto method, the results mentioned for the Taguchi method are still retained.
6. However, for the Taguchi-ABC method, the selected best parameters are G, F, and C/V, occurring in a tie of results for group A. For group B, the selected best parameters are C, V, and F. In contrast, for group C, the selected best parameter is V. nonetheless, in groups A, B, and C, the worst parameters are C, C/V, and F/V, respectively. To compare the output of the three methods, first, the representative best parameter among groups A, B, and C is V since it occurs in all three groups.
7. Interestingly, V (cutting velocity) is the best choice for the Taguchi and Taguchi-Pareto methods. Thus, overall, V (cutting velocity) ranked first and suggested for choice on further decisions on the turning operation of the Inconel X-750 material. Such decisions include planning for resource distribution and acquisition for the next planning period.

From an originality perspective, this article describes the aspect ratio approach, which has been successfully introduced to evaluate the parameters of turning operations using the Inconel X750 alloy for enhancement initiatives. Future research should introduce some economic factors into the computational structure for more robustness of the methods

REFERENCES

Ajibade, O.A., Agunsoye, J.O., & Oke, S.A. (2019). Optimisation of water absorption parameters of dual-filler filled composites using Taguchi and moderated Taguchi techniques. *Kufa Journal of Engineering*, *10*(2), 134-151.

Ajibade, O.A., Agunsoye, J.O., & Oke, S.A., (2021). Taguchi method and Taguchi-Pareto scheme to evaluate diffusivity during the development of orange peel epoxy composites. *Journal of Applied Science & Process Engineering*, *8*(1), 765-785.

Ajibade, O.A., Agunsoye, J.O., & Oke S.A. (2016). Tapped density optimisation for four agricultural wastes: Part II - Performance analysis, main effects of process parameters and Taguchi-Pareto. *Acta Periodica Technologica*, *47*, 129-142.

Barewar, S.D., Kotwani, A., Choughe, S.S., & Unune, D.R. (2021). Investigating a novel Ag/ZnO based hybrid nanofluid for sustainable machining of Inconel 718 under nanofluid based minimum quantity lubrication. *Journal of Manufacturing Processes*, *66*, 313-324.

Boubekri, N. & Shaikh, V.A. (2015). Minimum quantity lubrication (MQL) in machining: Benefits and drawbacks. *Journal of Industrial and Intelligent Information*, *3*(3), 205-209.

Cardwell, S. (2015). A sense of proportion: Aspect ratio and the framing of television space. *Critical Studies in Television: The International Journal of Television Studies*, 10(3), 83-100.

Chetan, Behera, B.C., & Rao, P.V. (2016). Application of nano fluids during minimum quality lubrication: a case study in turning process. *Tribology International*, *101*, 234-246.

Chinchanikar, S., Kore, S.S., & Hujaree, P. (2021). A review on nanofluids in minimum quantity imbrication machining. *Journal of Manufacturing Processes*, *68*, 56-70.

Das, A., Pradhan, O., Patel, S.K., & Das, S.R. (2019). Performance appraisal of various nanofluids during hard machining of AISI 4340 steel. *Journal of Manufacturing Processes*, *46*, 248-270.

Elsheikh, A.H, Elaziz, M.A., Das, S.R., Muthuramalingam, T., & Lu, S. (2021). A new optimized predictive model based on political optimizer for eco-friendly MQL-turning of AISI 4340 alloy with nano-lubricants. *Journal of Manufacturing Processes*, *67*, 562-578.

Esfe, M.H., Bahiraei, M., & Mir, A. (2020). Application of conventional and hybrid nano fluids in different matching processes: A critical review. *Advance in Colloid and Interface Science*, *282*, article 102199.

Gunantara, N. (2018). A review of multi-objective optimization: Method and its applications. *Cogent Engineering*, *5*(1), 3-5.

Joshi, K.K., Behera, R.K., & Anurag, K. (2018). Effect of minimum quantity lubrication with Al_2O_3 nanofluid on surface roughness and its prediction using hybrid fuzzy controller in turning operation of Inconel 600. *Materials Today: Proceedings*, *5*(9), 20660-20668.

Junankar, A.A., Parate, S.R., Dethe, P.K., Dhote, N.R., Gadkar, D.G., Gadkar, D.D., & Gaybhiye, S.A. (2021). A review: Enhancement of turning process performance by effective utilization of hybrid nanofluid and MQL. *Materials Today: Proceedings*, *38*, 44-47.

Junankar, A.A., Parate, S.R., Dethe, P.K., Dhote, N.R., Gadkar, D.G., Gadkar, D.D., & Gajbhiye, S.A. (2021). Optimization of bearing steel turning parameters under CuO and ZnO nanofluid-MQL using MCDM hybrid approach. *Materials Today: Proceedings*, *47*(14), 4292-4297.

Kannan, V. & Kannan, V. (2018). A comparative study on machinability characteristics in dry machining of inconel X-750 alloy using coated carbide inserts. *SAE Technical Paper*.

Khan, A.M., Gupta, M.L., Heg, H., Jamil, M., Mia, M., He, N., Song, Q., Liu, Z., & Pruncu, C.I. (2020). Energy-based cost integrated and sustainability assessment of Al-GnP hybrid nanofluid assisted turning of AISI 52100 steel. *Journal of Cleaner Production*, *257*, Article120502.

Kumar, M.S., & Krishna, V.M. (2020). An investigation on turning AISI 1018 steel with hybrid biodegradable nanofluid/MQL incorporated with combinations of CuO-Al_2O_3 nanoparticles. *Materials Today: Proceedings*, *24*(2), 1577-1584.

Marsh, C. (2018). *The mechanical properties and deformation behavior of heat treated versus as-received inconel X-750, Master's Thesis, Department of Mechanical Engineering*. College of Engineering and Computing, University of South Carolina, USA. Retrieved from https://scholarcommons.sc.edu/etd/4974.

Murali, K.V. & Varium, K.A. (2020). Investigation on influence of hybrid biodegradable nanofluids (CuO-ZnO) on surface roughness in turning AISI:1018 steel.

Materials Today: Proceedings, *24*, 1570-1576.

Oji, B.C. & Oke, S.A. (2020). Optimisation of bottling process using “hard” total quality management elements. *The TQM Journal*, *33*(2), 473-502.

Okanminiwei, L. & Oke, S.A. (2020). Optimisation of maintenance downtime for handling equipment in a container terminal using Taguchi scheme, Taguchi-Pareto method and Taguchi-ABC method. *Indonesian Journal of Industrial Engineering & Management*, *1*(2), 69-90.

Onwubolu, G. & Kumalo, T. (2001). Optimisation of multi pass turning operations with genetic algorithms. *International Journal of Production Research*, *39*(16), 3727-3745.

Padmini, R., Krishna, P.V., & Rao, G.K.M. (2016). Effectiveness of vegetable oil based nanofluids as potential cutting fluids in turning AISI 1040 steel. *Tribology International*, *94*, 490-501.

Petrovic, D. & Radovanici, M. (2013). Using genetic algorithms for optimization of turning machining process. *Journal of Engineering Studies and Research*, *19*(1), 47-55.

Purohit, Y.K., Gohane, G.M., Rachbhaai, J.S., Gupta P.M., & Sayed A.R. (2021). Performance evaluation of Cu nanofluid in bearing steel MQL based turning operation. *Materials Today: Proceedings*, *44*, 4309-4314.

Rahman, S.S., Ashraf, M.Z.I., Amin, A.K.M.N., Bashar, M.S., Ashik, M.F.K., & Kamruzzaman M. (2019). Tuning nanofluidsfor improved lubrication performance in turning biomedical grade titanium alloy. *Journal of Cleaner Production*, *206*, 180-196.

Sarikaya, M., Sirin, S., Yildirim, C.V., Kivad, T., & Gupta, M.K. (2021). Performance evaluation of whisker-reinforced ceramic tools under nano-sized solid lubricants assisted MQL turning of co-based Haynes 25 superalloy. *Ceramics International*, *47*(11), 15542-15560.

Sharma, P., Sidhub, S., & Sharma, J. (2015). Investigation of effects of nanofluids on turning of AISI D2 steel using minimum quantity lubrication. *Journal of Cleaner Production*, *108*, 72-79.

Singh, R.K, Sharma, A.K., Mandal, B.V., Gaurav, K., Nag, A., Kumar, A., Dixi,t A.R., Mandal, A., & Das, A.K. (2018). Influence of graphene-based nanofluid with minimum quantity lubrication on surface roughness and cutting temperature in turning operation. *Materials Today: Proceedings*, *5*(11), 24578-24586.

Singh, J. & Chatta, S.S. (2021). Tribological behavior of nanofluids under minimum quantity lubrication in turning of AISI 1055 steel. *Materials Today: Proceedings*, *41*, 825-832.

Sirin, S., Sarikaya, M., Yildirim, C.V., & Kivak, T. (2021). Machinability performance of nickel alloy X-70 with SiAlON ceramic cutting tool under dry, MQL and LBN mixed nanofluid-MQL. *Tribology International*, *153*, Article106673.

Special Metals. (2004). Inconel X-750, Publication No. SMC-067, Special Metals Corporation, www.specialmetals.com, Accessed 8th January, 2022.

Sridhara, V. & Satapathy, L.N. (2011). Al_2O_3–based nanofluids: A review. *Nanoscale Research Letters*, *6*, Article456.

Tanmaisaigeetha, C.H., Dash, A.K., Kavya, B., & Amrita, M. (2021). Analysis of hybrid nanofluids in machining AISI 4340 using minimum quantity lubrication. *Materials Today: Proceedings*, *43*(1), 579-586.

Ujiie, H., Tamano, Y., Sasaki, K., & Hori, T. (2001). Is the aspect ratio a reliable index for predicting the rupture of a saccular aneurysm? *Neurosurgery*, *48*(3), 495-503.

Ukamanal, M., Mishra, P.C., & Sahoo, A.L. (2018). Temperature distribution during AISI 316 steel turning under T_iO_2-water based nanofluid spray environment. *Materials Today: Proceedings*, *5*(9), 20741-20749.

Venkatesan, K., Patel, J.K, Raval, G.V., & Shaj H.V. 2018, A comparative study of tool wears in dry turning of Inconel X 750 and waspaloy, *Materials Today: Proceedings*, *5*, 13429-13437.

Venkatesan, K., Arun, T.M., Devendiran, S., Ghazaly, N.M., Sanjith, S., & Raghul, R. (2019c). Machinability study and multi-response optimization of cutting force, surface roughness and tool wear on CNC turned Inconel 617 superalloy using Al_2O_3 nanofluids in coconut oil. *Procedia Manufacturing*, *30*, 396-403.

Venkatesan, K., Devendiran, S., Ghazaly, N.M., Rahel, R., & Maghilan, T. (2019a). Optimization of cutting parameters on turning of Incoloy 800H using Al_2O_3 nanofluid in coconut oil. *Procedia manufacturing*, *30*, 268-275.

Venkatesan, K., Devendiran, S., Ghazaly, N.M., & Nishanth. (2019b). Application of Taguchi-response surface analysis to optimize the cutting parameters on turning of Inconel X-750 nano-fluids suspended Al_2O_3 in coconut oil. *Procedia Manufacturing*, *30*, 90-97.

Wang, X., Li, C., Zhang, Y., Ding, W., Yang, M., Gao, T., Cao, H., Xu ,X., Wang, D., Said, Z., Debnath, S., Jamil, M., & Ali H.M. (2020). Vegetable oil-based nanofluid minimum quantity lubrication turning: Academic review and perspectives. *Journal of Manufacturing Processes*, *59*, 76-97.

Yi, S., Mo, J., & Ding, S. (2019). Experimental investigation on the performance and mechanism of graphene oxide nanofluids in turning Ti-6AL-4V. *Journal of Manufacturing Processes*, *43*, 164-174.

Yi, S., Li, J., Zhi J., Wang, X., Mo, J., & Ding, S. (2020). Investigation of machining Ti-6Al-4V with graphene oxide nanofluids: Tool wear, cutting forces and cutting vibration. *Journal of Manufacturing Processes*, *49*, 35-49.

Yildirim, C.V. (2020). Investigation of hard turning performance of eco-friendly cooling strategies: Cryogenic cooling and nanofluid based MQL. *Tribology International*, *144*, Article106127.

Yildirim, C.V., Sarikaya, M., Kivak, K., & Sirin, S. (2019). The effect of addition of HBN nanoparticles to nanofluid MQL on tool wear patterns, tool life, roughness and temperature in turning of Ni-based Inconel 625. *Tribology International*, *134*, 443-456.

This page is intentionally left blank