Global Journal of Engineering and Technology Advances, 2020, 05(01), 053–059

Global Journal of Engineering and Technology Advances

Cross Ref DOI: 10.30574/gjeta

Journal homepage: http://www.gjeta.com

(REVIEW ARTICLE)

Response surface methodology and Taguchi method based applications – A Review

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Publication history: Received on 21 August 2020; revised on 08 October 2020; accepted on 14 October 2020

Article DOI: https://doi.org/10.30574/gjeta.2020.5.1.0062

Abstract

Response surface methodology (RSM) is usually applied together with a factorial design to reduce the cost of experimentation and is especially useful when there are more potential factors than money to study a response. It was designed as a tool to have a lot of (partial) answers with as few experiments as possible; to detect factors that influence a response, and whether they interact, as well as finding an optimum treatment within a specific setup. On the other hand, the Taguchi method is a statistical method, also called robust design method, to improve the quality of manufactured goods, and more recently also applied to engineering. This paper presents an extensive literature review on the concept of the RSM and Taguchi methods in solvent extraction, engineering optimization and several machining process parameters.

Keywords: Taguchi; Response surface methodology; Machining; Optimization.

1. Introduction

Response surface methodology (RSM) was initially developed by Box during early 1950s [1]. RSM is usually applied together with a factorial design to reduce the cost of experimentation and is especially useful when there are more potential factors than money to study a response. It was designed as a tool to have a lot of (partial) answers with as few experiments as possible; to detect factors that influence a response, and whether they interact, as well as finding an optimum treatment within a specific setup. Because it uses only linear relationships, there is no actual knowledge of the true relation linking a factor and the response, and it is quite poor at predicting actual data for example when you have a slope followed by plateau. Nonetheless, it can give a reasonably useful approximation.

RSM comprises a group of mathematical and statistical approaches in which the response of interest relies on several significant variables, and the aim of the method is to model and optimise this response [2]. In order to achieve this objective, linear or square polynomial equation are established to define the case study. The generalisability of much-published research in most of RSM problems, do not have the form of relationship between response and the independent variable. Therefore, the first step in applying the RSM is to find an approximation function between the input and the output. In most cases, a low-order polynomial was predicted by RSM. If the function yields a linear function relationship, between the input and the output, then the approximation function is the first order model [3]. The input and response can be indicated as $X_1, X_2, \dots X_k$, and (y) respectively as in Eq. (1).

$$y = f'(X)\beta + \varepsilon \qquad (1)$$

Where $X = (X_1, X_2, \dots X_k)', f(X)$ is a vector function of p elements that contains powers of $X_1, X_2, \dots X_k$ up to a certain degree denoted as d (> 1). For a first (d = 1) polynomial, the equation can be described as in (2)

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$$y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \varepsilon \quad (2)$$

On the other hand, if the model predicted a curvature, then a polynomial of higher degree is necessary to be used, such the second order model (Montgomery, 2008).

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum \sum_{i<j} \beta_{ij} X_i X_j + \sum_{i=1}^{k} \beta_{ii} {X_i}^2 + \varepsilon \quad (3)$$

Where $\boldsymbol{y}$ represents the predicted response, i represents the linear coefficient, j represents the quadratic coefficient, β represents the regression coefficient, k represents the number of factors and $\boldsymbol{\varepsilon}$ is a random experimental error assumed to have a zero mean [4].

RSM is widely used for multivariable optimization studies in several biotechnological processes such as optimization of media, process conditions, catalyzed reaction conditions, oxidation, production, fermentation, etc. [5][6][7][8][9] and [10]. It has also been used to determine the optimal values for process parameters such as pH, temperature, aeration, feeding rates in various processes [11] and [12]. Several applications of RSM are reviewed based on recent literature.

2. Response Surface Method Applied to Solvent Extraction

Response surface methodology is employed to study the effect of liquid: solid ratio, sodium chloride concentration and reaction time on the production of protein from germinant pumpkin seeds [13]. Regression analysis was performed on the data obtained. The most relevant variable was liquid-solid ratio. The coefficient determination (R^2) was good for the second-order model. A liquid-solid ratio of 30.2: 1 (v/w), a sodium chloride concentration of 4.26% and a reaction time of 18.1 min were found to be optimal for protein extraction from germinant pumpkin seeds.

Response surface methodology was used to optimize the process parameters for the extraction of chromium from aqueous solution of waste sodium dichromate recovered from the pharmaceutical industry wastewater using emulsion liquid membrane technique by [14]. The process parameters namely, feed concentration, pH, internal reagent concentration and surfactant concentration on the extraction of chromium were optimized using Box–Behnken design. The optimum conditions for the extraction of chromium (VI) were; feed concentration (224.04 ppm), pH (2.76), internal reagent concentration (0.71 N) and surfactant concentration (1.92%, w/w). At the optimized condition, the results showed the maximum chromium extraction as 92.50%.

Response surface methodology was also used to determine the optimum processing conditions that give maximum extraction yield, viscosity, hue and emulsion stability, as well as, minimum protein content for the gum extracted from *Lepidium perfoliatum* seed. Temperature (45–75 °C), processing time (1.5–3.5h), pH (5–8) and water to seed ratio (30:1–60:1) were the factors investigated [15]. Experiments were designed according to Central Composite Rotatable Design with these four factors, including central and axial points. For each response, a second-order polynomial model was developed using multiple linear regression analysis. Applying desirability function method, optimum operating conditions were found to be extraction temperature of 48.1 °C, pH of 8, water to seed ratio of 30:1 and process time of 1.5 h. At this optimum point, the results showed that the extraction yield, viscosity, protein content, hue and emulsion stability were 17.36%, 463.07 mPas, 2.84%, 60.47 and 88.96 %, respectively.

Response surface methodology was to determine optimum conditions for extraction of protein from red pepper seed meal [16]. A central composite design including independent variables such as temperature (30, 35, 40, 45 and 50 °C), pH (7.0, 7.5, 8.0, 8.5 and 9.0), extraction time (20, 30, 40, 50 and 60 min) and solvent/meal ratio (10:1, 15:1, 20:1, 25:1 and 30:1 v/w) was used. Selected response (dependent variable) which evaluates the extraction process was protein yield and the second-order model obtained for protein yield revealed coefficient of determination of 96.7%. Protein yield was primarily affected by pH and solvent/meal ratio. Maximum yield was obtained when temperature, pH, mixing time and solvent/ meal ratio were 31 °C, 8.8, 20 min, 21:1 (v/w), respectively. The adequacy of the model was confirmed by extracting the protein under optimum values given by the model.

Preliminary characterization of polysaccharides from *Phellinus igniarius* and optimization of extraction process was presented by [17] using Response surface methodology. The analysis showed that the extraction temperature and ratio of mycelia to water significantly affected extraction yield. The optimal conditions were extraction temperature 70 °C, extraction time 1.5 h and the ratio of mycelia to water 1:6.2. Under these conditions, the maximal yield of crude intracellular polysaccharide (IPS) from mycelia was 50.39 ± 0.41 mg/g, which agreed with model predictions.

Application of the response surface methodology for the optimization of solvent extraction to recovery of acetic acid from black liquor derived from *Typha latifolia* pulping process was done by [18]. Following RSM optimization, the maximum extraction yields obtained for the organic acids under the optimal conditions were 71.7%, 75.1%, and 65.0% for acetic acid, formic acid, and lactic acid, respectively. For the fermentation process, the sugar concentrations in *Typha latifolia* pulp black liquor were determined. Sugars are not greatly affected by Liquid-liquid extraction (LLE) with an extractant. The study provided first-hand knowledge regarding their method and provides an insight into the complex and conflicting parameters governing the LLE process.

3. Response Surface Methodology Applied to Optimization of Systems

The RSM method also finds application in the optimization of different energy systems by effectively optimizing the system's operational factors. Such application is found on the optimization of the kinetic study of Fischer-Tropsch synthesis using SiO_2 supported bimetallic Co-Ni catalyst [19]. They chose the process parameters of syngas ratio, operational pressure, and reaction temperature as independent variables in central composite design and developed a quadratic model for process optimization and statistical experimental designs. It was found that the syngas ratio, operational pressure, and reaction temperature are significant to CO conversion and light olefin (C2-C4) selectivity.

Similarly, [20] used RSM in the optimization of cadmium adsorption by shoe waste: The effect of operating variables such as metal ions concentration (20–820 mg/L), adsorbent dosage (0.1–2.1 g/L) and solution pH (1–9) and contact time (288–1440sec) were modelled. The results suggested that waste shoe can be used for the Cd (II) adsorption from wastewater.

Also [21] applied the response surface methodology to optimize the extracellular fungal mediated nanosilver green synthesis. Silver nanoparticles (AgNPs) were biosynthesized effectively in terms of the factors impacting silver ion (Ag^+) reduction to metallic nanosilver (Ag^0) using culture filtrate under shaking condition. The results of statistics calculations revealed that 2mM silver nitrate and 28% (v/v) of culture filtrate at pH 7.0 for 34 h were the optimum values for AgNPs biosynthesis. The characterization of the produced AgNPs was conducted using electron microscopy, energy dispersive X-ray analysis, UV/visible spectrophotometry and Fourier transform infrared spectroscopy. Round to oval AgNPs were detected with aspects of transmission electron microscopy (TEM) within diameter range of 4– 16 nm. The results of the study could help in developing a reliable ecofriendly, simple, and low cost process for microbial assisted AgNPs green synthesis especially with the continuous increase in its application fields.

Again [22] applied the response surface methodology for optimization of biodiesel production by trans-esterification of soybean oil with ethanol. The combined effects of temperature, catalyst concentration, reaction time and molar ratio of alcohol in relation to oil were investigated and optimized. The results showed the optimum conditions for the production of ethyl esters as: mild temperature at 56.7 °C, reaction time in 80 min, molar ratio at 9:1 and catalyst concentration of 1.3 M.

Subsequently [23] presented an optimization of the methanolysis of lard oil in the production of biodiesel with response surface methodology. The study showed that lard oil as a low cost feedstock is a good source of raw material for biodiesel production and a sustainable biodiesel production could be achieved with proper optimization of the process variables.

Also [24] applied response surface methodology to optimize the removal of lead ion by *Aspergillus niger* in an aqueous solution. Experiments were conducted based on a rotatable central composite design and analysed using RSM. The biosorption process was investigated as a function of three independent factors viz. initial solution pH (2.8–7.2), initial lead concentration (8–30 mg/l) and biomass dosage (1.6–6 g/l). The optimum conditions for the lead biosorption were found to be 3.44, 19.28 mg/l and 3.74 g/l, respectively, for initial solution pH, initial lead ion concentration and biomass dosage.

Again, [25] developed a fourth order RSM model for predicting surface roughness values in milling mold surfaces made of Aluminum (7075-T6) material. In generating the RS model statistical RSM was utilized. The accuracy of the RS model was verified with the experimental measurement. The accuracy error was found to be insignificant (2.05%). The developed RS model was further coupled with a developed GA to find the optimum cutting condition leading to the least surface roughness value. The predicted optimum cutting condition was validated with an experimental measurement. It was found that GA prediction correlates very well with the experiment.

4. Taguchi Method Based Applications

The Taguchi method is a statistical method, also called robust design method, meant to improve the quality of manufactured goods and more recently also applied to engineering [26], marketing and advertising [27] and biotechnology [28].

The Taguchi Method is a process/product optimization method that is based on 8-steps of planning, conducting and evaluating results of matrix experiments to determine the best levels of control factors. The primary goal is to keep the variance in the output very low even in the presence of noise inputs. Several applications of the Taguchi method can be seen in machining operations and engineering optimization.

5. Taguchi method applied to machining operations

Taguchi method was applied in the analysis of hard machining of Titanium Alloy by [29]. They optimized the cutting parameters and obtained the optimum surface roughness and tool wear.

Also [30] applied the Taguchi method for determining optimum surface roughness in wire electric discharge machining of powder metallurgy (PM) cold worked tool steel (Vanadis-4E). They obtained an optimal set of machining process variables that yields the optimum quality features to machine components engendered by wire electrical discharge machine process.

Subsequently [31] investigated the effect of the machining parameters on material removal rate using Taguchi method in end milling of Steel Grade EN19. The analysis results revealed that the feed rate and depth of cut are main affecting parameter of metal removing rate. Again [32] presented Taguchi design optimization of machining parameters on the CNC end milling process of halloysite nanotube with aluminium reinforced epoxy matrix (HNT/Al/Ep) hybrid composite. The result shows that the application of the Taguchi method can determine the best combination of machining parameters that can provide the optimal machining response conditions which are the lowest surface roughness and lowest cutting force value.

6. Taguchi method applied to optimization

The Taguchi method was used in the optimization of the process parameters affecting biosorption and Analysis of Mean (ANOM) approach for maximizing the percentage removal of copper and nickel by growing Aspergillus specie in batch reactor by [33]. The results showed the optimized conditions as 15 % v/v inoculum concentration, 50 mg l^{-1} concentration of copper/nickel, pH 4 and temperature 30 °C. Also [34] applied the Taguchi method in the optimization of wastewater treatment using spiral-wound reverse osmosis element. The flux was improved to 69 l/m^2 h by setting the control factors according to the Taguchi method. The technique showed that concentration of feed solution has the highest contribution in rejection of a solution containing nitrate, nitrite, sulfite and phosphate. Further [35] applied the Taguchi method to investigate the effect of reductive leaching parameters and mechanical pre-treatment of ilmenite on nano synthetic rutile synthesis. The characterization of products indicated that the prepared powder with milling time 40min, temperature 100 ∘C, ilmenite to hydrochloric acid mass ratio 1:12.8 and ilmenite to iron powder mass ratio 1:0.05 had particles size of less than 100nm. The analysis further confirmed that synthetic rutile nano powder had 91.1% TiO_2.

Subsequently [36] applied the Taguchi method in the optimization of the laser-cutting process. A high figure-of-merit was obtained using the treatment conditions of beam power of 415 W, oxygen pressure of 0.12 MPa, focal position of 1/4, focal length of 63.5 mm and cutting speed of 0.8 m/min. Again [37] applied the Taguchi method in the optimization of end milling parameters. The study shows that the Taguchi method is suitable to solve the stated problem with minimum number of trials as compared with a full factorial design. Also [38] applied the Taguchi method in the optimization of cutting parameters for surface roughness in turning. It was found that the parameter design of the Taguchi method provides a simple, systematic and efficient methodology for the optimization of the cutting parameters. Further study showed that [39] used the Taguchi method for optimization of finishing conditions in magnetic float polishing (MFP). The experimental results indicate that within the range of parameters evaluated, a high level of polishing force, a low level of abrasive concentration and a high level of polishing speed are desirable for improving both arithmetic average and peak-to-valley height. Again [40] used the Taguchi method to optimize the differential evolution algorithm parameters for minimizing the workload smoothness index in simple assembly line balancing. Also [41] used the Taguchi method for the optimization of processing variables to prepare porous scaffolds by combined melt mixing/particulate leaching. The results revealed that the mixing temperature had the highest effect on mechanical properties. Subsequently [42] applied the Taguchi method based optimisation of drilling parameters in drilling of AISI 316 steel with PVD monolayer and multilayer coated high speed steel (HSS) drills. The results of the confirmation experiments showed that the Taguchi method was notably successful in the optimisation of drilling parameters for better surface roughness and thrust force. Again [43] performed a Taguchi optimization of process parameters in friction stir processing of pure Mg. It was shown that tilt angle and rotational speed as well as travel speed have the most significant effect on hardness value of magnesium.

7. Conclusion

Response surface methodology (RSM) is usually applied together with a factorial design to reduce the cost of experimentation and is especially useful when there are more potential factors than money to study a response. It was designed as a tool to have a lot of (partial) answers with as few experiments as possible, to detect factors that influenced a response and whether they interact as well as finding an optimum treatment within a specific setup. The Taguchi method is a statistical method, also called robust design method to improve the quality of manufactured goods and more recently also applied to engineering. A review of the application of both the RSM and Taguchi method in solvent extraction, engineering optimization and several machining process parameters is presented in the light of current engineering practice.

References

[1] Bezerra MA, Santelli RE, Oliveira EP, Villar LS, Escaleira LA. (2008). Response surface methodology (RSM) as a tool for optimization in analytical chemistry. Talanta, 76(1), 65-77.

[2] Montgomery, D. C. (2008). Design and analysis of experiments. John Wiley and Sons; 2008.

[3] Kiran B, Pathak K, Kumar R, Deshmukh D. (2016). Statistical optimization using central composite design for biomass and lipid productivity of microalga: a step towards enhanced biodiesel production. Ecol Eng 92(1), 73-81.

[4] Ghafari, S., Aziz, H. A., Isa, M. H., Zinatizadeh, A. A. (2009). Application of response surface methodology (RSM) to optimize coagulation–flocculation treatment of leachate using poly-aluminum chloride (PAC) and alum. J Hazard Mater 163(1), 650–660.

[5] Beq, Q. K., R. K. Saxena, and R. Gupta (2002). ''Kinetic Constants Determination for an Alkaline Protease from Bacillus mojavensis Using Response Surface Methodology,'' Biotechnol. Bioeng., 78, 289.

[6] Chang, Y. C., C. L. Lee, and T. M. Pan (2006). ''Statistical Optimization of Media Components for the Production of Antrodia cinnamomea AC0623 in Submerged Cultures,'' Appl. Microbiol. Biotechnol., 72, 654.

[7] Kristo, E., C. G. Biliaderis, and N. Tzanetakis (2003). ''Modeling of the Acidification Process and Rheological Properties of Milk Fermented with a Yogurt Starter Culture Using Response Surface Methodology,'' Food Chem., 83, 437.

[8] Lai, L. S. T., C. C. Pan, and B. K. Tzeng (2003). ''The Influence of Medium Design on Lovastatin Production and Pellet Formation with a High-Producing Mutant of Aspergillus terreus in Submerged Cultures,'' Process Biochem., 38, 1317.

[9] Soo, E. L., A. B. Salieh, and M. Basri (2004). ''Response Surface Methodological Study on Lipasecatalyzed Synthesis of Amino Acid Surfactants,'' Process Biochem., 39, 1511.

[10] Wang, Y. X. and Z. X. Lu (2005), ''Optimization of Processing Parameters for the Mycelial Growth and Extracellular Polysaccharide Production by Boletus spp. ACCC 50328,'' Process Biochem., 40, 1043.

[11] Mannan, S. and A. Fakhrul-Razi, and Md. Z. Alam (2007). ''Optimization of Process Parameters for the Bioconversion of Activated Sludge by Penicillium corylophilum, Using Response Surface Methodology,'' J. Environ. Sci., 19, 23.

[12] Pan, C. M., Y. T. Fan, Y. Xing, H. W. Hou, and M. L. Zhang(2008). ''Statistical Optimization of Process Parameters on Biohydrogen Production from Glucose by Clostridium sp. Fanp2,'' Bioresource Technol., 99, 3146.

[13] Quanhong, L., and Caili, F. (2005). Application of response surface methodology for extraction optimization of germinant pumpkin seeds protein. Food Chemistry, 92(4), 701-706.

[14] Rajasimman, M., and Karthic, P. (2010). Application of response surface methodology for the extraction of chromium (VI) by emulsion liquid membrane. Journal of the Taiwan Institute of Chemical Engineers, 41(1), 105-110.

[15] Koocheki, A., Taherian, A. R., Razavi, S. M. A., and Bostan, A. (2009). Response surface methodology for optimization of extraction yield, viscosity, hue and emulsion stability of mucilage extracted from Lepidium perfoliatum seeds. Food Hydrocolloids, 23(8), 2369-2379.

[16] Firatligil, E., and Evranuz, O. (2010). Response surface methodology for protein extraction optimization of red pepper seed (Capsicum frutescens). LWT - Food Science and Technology, 43(2), 226–231.

[17] Guo, X., Zou, X., and Sun, M. (2010). Optimization of extraction process by response surface methodology and preliminary characterization of polysaccharides from Phellinus igniarius. Carbohydrate Polymers, 80(2), 344-349.

[18] Kim, G. H., Park, S. J., and Um, B. H. (2016). Response surface methodology for optimization of solvent extraction to recovery of acetic acid from black liquor derived from Typha latifolia pulping process. Industrial Crops and Products, 89(1), 34-44.

[19] Sun, Y., Wei, J., Zhang, J. P., and Yang, G. (2016). Optimization using response surface methodology and kinetic study of Fischer-Tropsch synthesis using SiO_2 supported bimetallic Co-Ni catalyst. Journal of Natural Gas Science and Engineering 28(1), 173-183.

[20] Iqbal, M., Iqbal, N., Bhatti, I. A., Ahmad, N., and Zahid, M. (2016). Response surface methodology application in optimization of cadmium adsorption by shoe waste: A good option of waste mitigation by waste. Ecological Engineering, 88(2), 265-275.

[21] Othman, A. M., Elsayed, M. A., Elshafei, A. M., and Hassan, M. M. (2017). Application of response surface methodology to optimize the extracellular fungal mediated nanosilver green synthesis. Journal of Genetic Engineering and Biotechnology, 15(2), 497-504.

[22] Silva, G. F., Camargo, F. L., and Ferreira, A. L. O. (2011). Application of response surface methodology for optimization of biodiesel production by transesterification of soybean oil with ethanol. Fuel Processing Technology, 92(3), 407-413.

[23] Ezekannagha, C. B., Ude, C. N., and Onukwuli, O. D. (2017). Optimization of the methanolysis of lard oil in the production of biodiesel with response surface methodology. Egyptian Journal of Petroleum, 26(4), 1001-1011.

[24] Amini, M., Younesi, H., Bahramifar, N., Lorestani, A. A. Z., Ghorbani, F., Daneshi, A., and Sharifzadeh, M. (2008). Application of response surface methodology for optimization of lead biosorption in an aqueous solution by Aspergillus niger. Journal of Hazardous Materials, 154(1-3), 694-702.

[25] Öktem, H., Erzurumlu, T., & Kurtaran, H. (2005). Application of response surface methodology in the optimization of cutting conditions for surface roughness. Journal of Materials Processing Technology, 170(1-2), 11-16.

[26] Rosa, J. L., Robin, A., Silva, M. B., Baldan, C. A., Peres, M. P. (2008). Electrodeposition of copper on titanium wires: Taguchi experimental design approach. Journal of Materials Processing Technology. 209: 1181-1188.

[27] Rao, R. S., Kumar, C. G., Prakasham, R. S., Hobbs, P. J. (2008). The Taguchi methodology as a statistical tool for biotechnological applications: A critical appraisal. Biotechnology Journal. 3 (4): 510-523.

[28] Selden, P. H. (1997). Sales Process Engineering: A Personal Workshop. Milwaukee, Wisconsin: ASQ Quality Press. p. 237.

[29] Ravi Kumar, S. M., and Kulkarni, S. K. (2017). Analysis of Hard Machining of Titanium Alloy by Taguchi Method. Materials Today: Proceedings, 4(10), 10729-10738.

[30] Sudhakara, D., and Prasanthi, G. (2014). Application of Taguchi Method for Determining Optimum Surface Roughness in Wire Electric Discharge Machining of P/M Cold Worked Tool Steel (Vanadis-4E). Procedia Engineering, 97(2), 1565-1576.

[31] Parashar, V., and Purohit, R. (2017). Investigation of the effects of the Machining Parameters onMaterial Removal Rate using Taguchi method in End Milling of Steel Grade EN19. Materials Today: Proceedings, 4(2), 336-341.

[32] Pang, J. S., Ansari, M. N. M., Zaroog, O. S., Ali, M. H., and Sapuan, S. M. (2014). Taguchi design optimization of machining parameters on the CNC end milling process of halloysite nanotube with aluminium reinforced epoxy matrix (HNT/Al/Ep) hybrid composite. HBRC Journal, 10(2), 138-144.

[33] Pundir, R., Chary, G. H. V. C., and Dastidar, M. G. (2016). Application of Taguchi method for optimizing the process parameters for the removal of copper and nickel by growing Aspergillus sp. Water Resources and Industry. doi:10.1016/j.wri.2016.05.001.

[34] Madaeni, S. S., and Koocheki, S. (2006). Application of taguchi method in the optimization of wastewater treatment using spiral-wound reverse osmosis element. Chemical Engineering Journal, 119(1), 37-44.

[35] Akhgar, B. N., Pazouki, M., Ranjbar, M., Hosseinnia, A., and Salarian, R. (2012). Application of Taguchi method for optimization of synthetic rutile nano powder preparation from ilmenite concentrate. Chemical Engineering Research and Design, 90(2), 220-228.

[36] Tam, S. C., Lim, L. E. N., and Quek, K. Y. (1992). Application of Taguchi methods in the optimization of the laser-cutting process. Journal of Materials Processing Technology, 29(1-3), 63-74.

[37] Ghani, J., Choudhury, I., and Hassan, H. (2004). Application of Taguchi method in the optimization of end milling parameters. Journal of Materials Processing Technology, 145(1), 84-92.

[38] Nalbant, M., Gökkaya, H., and Sur, G. (2007). Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning. Materials & Design, 28(4), 1379-1385.

[39] Jiang, M., and Komanduri, R. (1997). Application of Taguchi method for optimization of finishing conditions in magnetic float polishing (MFP). Wear, 213(1-2), 59-71.

[40] Mozdgir, A., Mahdavi, I., Badeleh, I. S., and Solimanpur, M. (2013). Using the Taguchi method to optimize the differential evolution algorithm parameters for minimizing the workload smoothness index in simple assembly line balancing. Mathematical and Computer Modelling, 57(1-2), 137-151.

[41] Scaffaro, R., Sutera, F., and Lopresti, F. (2017). Using Taguchi method for the optimization of processing variables to prepare porous scaffolds by combined melt mixing/particulate leaching. Materials & Design, 131(1), 334-342.

[42] Kıvak, T., Samtaş, G., and Çiçek, A. (2012). Taguchi method based optimisation of drilling parameters in drilling of AISI 316 steel with PVD monolayer and multilayer coated HSS drills. Measurement, 45(6), 1547-1557.

[43] Ahmadkhaniha, D., Heydarzadeh Sohi, M., Zarei-Hanzaki, A., Bayazid, S. M., and Saba, M. (2015). Taguchi optimization of process parameters in friction stir processing of pure Mg. Journal of Magnesium and Alloys, 3(2), 168-172.