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DETERMINATION OF MATERIAL FOR SHAFT DESIGN USING TOPSIS BASED TAGUCHI METHOD

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ABSTRACT
The shaft is a mechanical accessory where many applications like machines, automobiles, aircrafts etc., must have a proper design of the shaft, in-order to have the efficient transmission of power from one element to another. For the design of shaft an appropriate range of evaluation, general product form and processing methods for material must be made. The selection of material should be done by using multiple attribute decision methods (MADM). In this paper, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) based Taguchi method is proposed in order to decide a suitable material by considering different attributes and graphical representations are made for different attributes verse materials and vice versa.

KEYWORDS: Shaft; Materials; Design constraints; TOPSIS; Taguchi method.

INTRODUCTION
A Shaft is a mechanical device in which almost all machines have rotating parts and has a circular cross section. Normally the Shaft transfers the power from one end to another, thus they subjected to torque and are to be acclaimed from axles for support rotating moments [1-3]. A Product DFMA is designed by engineers for evaluation of overall manufacturing. DFMA process is composed of design for assembly (DFA) and design for manufacturing (DFM). By these methods the user can estimate the costs and information about materials used in manufacturing [2]. The above methods mainly have process control of materials, Product, process, properties and performance. The Figure 1 shows the cyclic process of manufacturing in order to have a correct analysis and optimizes product Material Engineering mainly focuses on the optimization of materials according to different applications in high-end. Considering different properties and characteristics of material modelling is essential in relating mechanical, chemical and thermal impacts [4]. According to the properties only the way of material will change in the usage for a specific application, materials like metals, alloys, polymers, ceramics and high-ended properties based materials will give reliability and lifespan of components during operation.

Taguchi methods are to advance the nature of fabricated equipments and recently it is also applied to many engineering fields. They are originally recycled in engineering fields which are suitable and regular strategy will not contribute for multiple attributes by default. For the analysis of multiple attributes a hybrid system is proposed for a multiple attribute decision making, such as TOPSIS a technique used for order preference by similarity to ideal solution. In this study, we aim to show the usability of the TOPSIS based Taguchi method to solve material used for design of shaft with multi attribute optimization

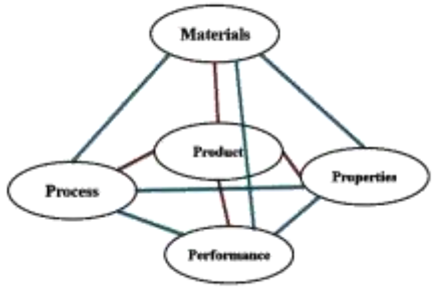

Fig.1 Cyclic Process of Manufacturing a Product

DESIGN OF SHAFT

Shafts are usually cylindrical machine component that transmits power. Occurrence of direct shearing stress due to twisting and bending stress due to bending will be for a given of the shaft. The shaft is designed on the basis of strength and its rigidity and stiffness. Shafts are subjected from the axles but only to bending loads and will not transfer power and torque. The Figure 2 represents the materials used in manufacturing industries from BC to date.

The Shaft is linked with different ways which will be flexible. Shaft materials should posses with low sensitivity, High strength and affective Machinability. As torque transmitted by shaft remains constant for a long time, the shearing stress on the shaft cross-section changes much less frequently [5]. According to Consumers and Users any product will high expectations with many attributes like low life-cycle cost, Good Safety, Higher performance, low impact on the environment, Easy in maintenance, Improved reliability etc. For the better management and better gains Consumers (Users) expectations must be satisfied. Every System will have regulations for making specialized and standardization a product. The Main standards are categorized as Company & good practice standards, Government regulations& standards, Consensus & consumer expectation standards

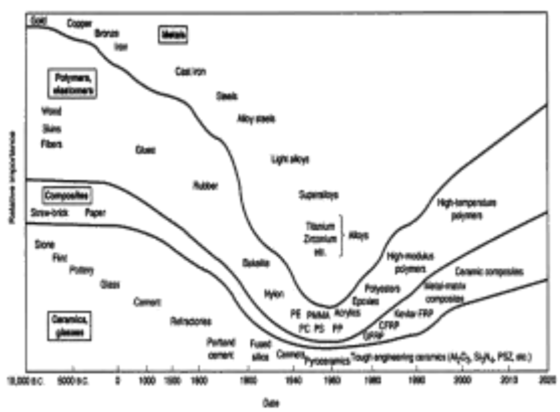

Fig.2 Materials from BC to date

For the better gains and good product along with above attributes Laboratory analysis must be made for the product. It includes Initial analysis, analytical documentation, Material Inspection, Fractographic test, Metallurgical analysis, Mechanical properties, Evidence analysis, Preparation of the report [6].

For the better gains and good product mechanical properties play a major role [7]. In metals, the properties which has to satisfy as per the standard values are Modulus of elasticity, Ductility, Fatigue strength, Impact strength, Coefficient of thermal expansion, Density, Yield strength, Shear strength, Tensile strength, Thermal conductivity, toughness etc and in polymers, the properties like Stability, Stiffness, Chemical, absorption & electrical resistance etc.

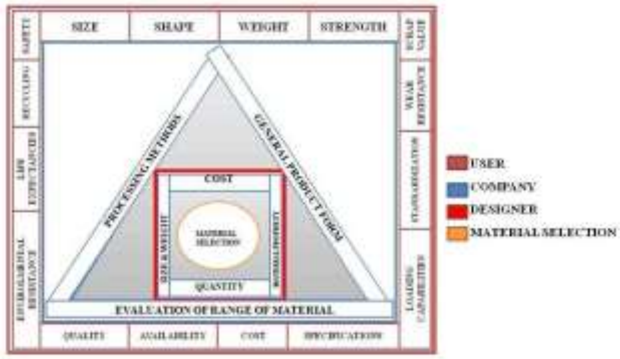

Fig.3 Analytical Process for Selection of Material for Design

Above Fig.3 is an analytical approach for selection of material. Initial Considerations are done according to the Users and Consumers, in the above fig all the attributes are represented as per user's requirements [8,9]. According to the User desire and company's availability among all three attributes are considered at company levels. Company will assign the needs to design engineer, for the better product output design will consider four attributes as shown in the figure. Considering all the attributes selection of material is done for any product manufacturing (shaft)

Proposed Methodology :Topsis based Taguchi

TOPSIS is a multi-criteria decision analysis method. It is based on the approach that chosen alternative should have the shortened measurable distance from the positive solution and the longest measurable distance from the negative ideal solution [10-12]. Normalization is needed as the specifications are usually of incompatible measurable in multi-criteria problems. TOPSIS is the best method to find out the ideal solution of the problem.

TOPSIS based Taguchi optimization is used to combine the multiple performance characteristics into a single value that can then be used as the single optimization function [13,14]. The first step is to make simulation runs, which are executed by following the experimental structure of the selected orthogonal array. While Eqn. (1) is used for "smaller-the-better", Eqn. (2) is applied for "larger-the-better".

$$\xi_{ij} = -10\log\left(\frac{1}{k}\sum_{n=1}^{k} y_{ijn}^2\right) \qquad (1)$$

$$\xi_{ij} = -10\log\left(\frac{1}{k}\sum_{n=1}^{k} \frac{1}{y_{ijn}^2}\right) \qquad (2)$$

Step 1: Determine the attributes that alter the selection of material
Step 2: Formulating the design matrix using the collected data.
Step 3: Compute the Taguchi ratios for all attributes using Eqn. (1), (2).
Step 4: Enter the values of Taguchi ratios at attributes as inputs as shown in Eqn. (3).

$$D = \begin{bmatrix} \xi_{11} & \xi_{12} & \xi_{13} & \cdots & \xi_{1n} \\ \xi_{21} & \xi_{22} & \xi_{23} & \cdots & \xi_{2n} \\ \xi_{31} & \xi_{32} & \xi_{33} & \cdots & \xi_{3n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ . & . & . & . & . \\ \xi_{m1} & \xi_{m2} & \xi_{m3} & \cdots & \xi_{mn} \end{bmatrix} \qquad (3)$$

Step 5: Computing normalized decision matrix using Eqn. (4).

$$\xi_{ij}^* = \xi_{ij} \Big/ \sqrt{\sum_{i=1}^{n} \xi_{ij}^{\,2}} \quad i = 1, 2, \ldots\ldots, m, j = 1, 2, \ldots\ldots, n \quad (4)$$

Step 6: Construct the weighted normalized decision matrix using Eq. (5), (6) & (7).

$$W_j = V_j / \sum_{j=1}^{m} V_j \ \& \ \sum_{j=1}^{m} w_j = 1 \quad (5)$$

$$V_j = (1/n) \sum_{i=1}^{n} \left(\xi_{ij}^* - (\xi_{ij}^*)_{mean} \right)^2 \quad (6)$$

$$\xi_{ij} = \xi_{ij}^* \, w_j \quad (7)$$

Step 7: Determine the ideal solution (A^+) and negative-ideal solution (A^-)

$$A^+ = \{v_1^+, \dots \dots \dots, v_m^+\} = \{(max v_{ij} \backslash j \epsilon I'), (min v_{ij} \backslash j \epsilon I'')\} \quad (8)$$

$$A^- = \{v_1^-, \dots \dots \dots, v_m^-\} = \{(min v_{ij} \backslash j \epsilon I'), (max v_{ij} \backslash j \epsilon I'')\} \quad (9)$$

I'= {j=1, 2 … n | j}: Associated with the beneficial attributes
I"= {j=1, 2… n | j}: Associated with non-beneficial adverse attributes
Step 8: Calculate the distance of scenario ***i*** to the ideal solution **(D_i^+)**, and from the negative ideal solution **(D_i^-)** using Eqn. (10), (11)

$$D_i^+ = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^+)^2}, i = 1, 2, \dots n \quad (10)$$

$$D_i^- = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^-)^2}, i = 1, 2, \dots n \quad (11)$$

Step 9: Calculate the Ranking score (***C_i*****) using Eqn. (12).

$$C_i^* = D_i^+ / (D_i^+ + D_i^-) \quad i = 1, 2, \dots n \qquad (12)$$

Step 10: Determine the optimal value to maximize function: The optimal value is finally determined, in view of the fact that a larger TOPSIS value indicates better quality. Taguchi method is to be applied finally to evaluate this optimal setting (by maximizing the TOPSIS index).

DISCUSSIONS

For the selection of material data is collected for a few materials as shown in Table 1. Step by step procedure is done for the proposed methodology as shown in Appendix-I. The graphical representations Figure 4, 5, 6 & 7 will give a clear idea for the best material among individual attributes for the collected data. According to the collected data of different materials with specific attributes, the proposed methodology is applied and decision for the selection of material in designing a shaft. From the collected data the order of decision making is Steels, Titanium and its alloys, Aluminum and its alloys, Ceramics, Carbon fibers and Kevlar fibers after applying the proposed methodology.

CONCLUSION

In this paper, TOPSIS based Taguchi method is applied for the selection of material for the design of the shaft. As the shaft is the major device in the smooth running of a machine. Since the proposed methodology, data are collected as per the sources given by manufacturing industries for each material. Among all the materials, steels, aluminum alloys, Titanium alloys, Ceramics, Carbon Fibers and Kevlar Fibers are considered with attributes Modulus of Elasticity (E) (GPA), Yield Stress (Y) (MPa), Ultimate Tensile Strength (UTS) (MPa), Poisson's ratio (ν) and Density (ρ). Analysis is done for having a decisive material as result for the design of the shaft for the smooth controlling of any machine according to the application. On the other hand, with the change of materials according to the applications we can get a decisive material for the application as the proposed methodology give the best decision in selecting of material.

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Graphical representations and discussions also demonstrated that materials which are used for the design of the shaft can be selected or decided for manufacturing of the shaft.

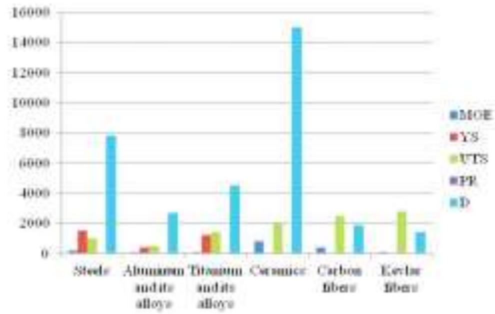

Fig.4 Graphical representation for Collected Data

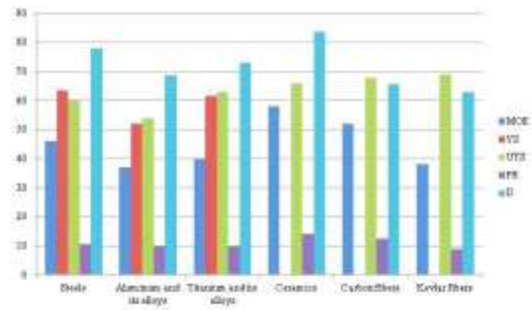

Fig.5 Graphical representation for Taguchi Data

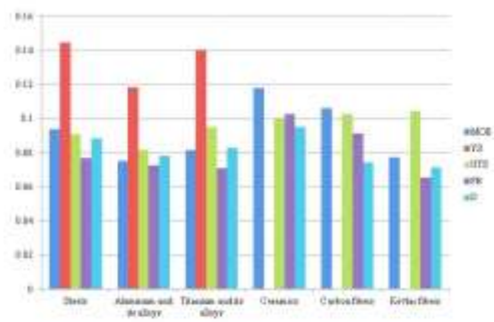

Fig.6 Graphical representation for Topsis-Taguchi Data

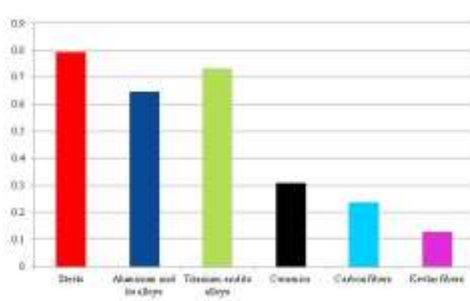

Fig.7 Graphical representation for Result of Proposed Method

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APPENDIX-I

Table 1: Collected data for selection of material

Materials	MOE	YS	UTS	PR	D
Steels	200	1500	1000	0.30	7850
Aluminum and its alloys	70	400	500	0.32	2700
Titanium and its alloys	100	1200	1400	0.33	4500
Ceramics	800	0	2000	0.2	15000
Carbon fibers	400	0	2500	0.24	1900
Kevlar fibers	80	0	2800	0.36	1400

MOE=Modulus of Elasticity (E) (GPa), YS=Yield stress (Y) (MPa), UTS=Ultimate Tensile Strength (UTS) (MPa), PR=Poisson's ratio (ν), D=Density (ρ) (kg/m3)

Applying Taguchi's ratio for the above data according to the considerations "smaller-the-better", "larger-the-better" with Eqns gives Table 2. $\xi_{ij} = -10\, log\left(\frac{1}{k}\sum_{n=1}^{k} y_{ijn}^2\right)$, $\xi_{ij} = -10\, log\left(\frac{1}{k}\sum_{n=1}^{k} \frac{1}{y_{ijn}^2}\right)$

Table 2: Taguchi based data for selection of material

Materials	MOE	YS	UTS	PR	D
Steels	46.02059991	63.52182518	60	10.45757491	77.8973931
Aluminum and its alloys	36.9019608	52.04119983	53.97940009	9.897000434	68.6272753
Titanium and its alloys	40	61.58362492	62.92256071	9.629721202	73.0642503
Ceramics	58.06179974	0	66.02059991	13.97940009	83.5218252
Carbon fibers	52.04119983	0	67.95880017	12.39577517	65.575072

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Kevlar fibers	38.06179974	0	68.94316063	8.873949985	62.9225607

MOE=Modulus of Elasticity (E) (GPa), YS=Yield stress (Y) (MPa), UTS=Ultimate Tensile Strength (UTS) (MPa), PR=Poisson's ratio (ν), D=Density (ρ) (kg/m3)

For the Table 2 normalization is done and normalized decision matrix is computed using Eqn $\xi_{ij}^* = \frac{\xi_{ij}}{\sqrt{\sum_{i=1}^{n} \xi_{ij}^2}}$

Table 3: Normalized Decision matrix

Materials	MOE	YS	UTS	PR	D
Steels	0.409857086	0.618853919	0.385668299	0.387618422	0.439942
Aluminum and its alloys	0.328646957	0.507005275	0.346969057	0.366840278	0.387587
Titanium and its alloys	0.356237934	0.599971231	0.404453949	0.356933359	0.412645
Ceramics	0.51709539	0	0.424367541	0.518157704	0.471707
Carbon fibers	0.463476238	0	0.436825914	0.459459373	0.370349
Kevlar fibers	0.338976423	0	0.443153191	0.328920091	0.355368

MOE=Modulus of Elasticity (E) (GPa), YS=Yield stress (Y) (MPa), UTS=Ultimate Tensile Strength (UTS) (MPa), PR=Poisson's ratio (ν), D=Density (ρ) (kg/m3)

From Table 3 weighted normalized decision matrix is computed using

$$W_j = {V_j}\Big/{\sum_{j=1}^{m} V_j} \quad V_j = \left({1}/{n}\right) \sum_{i=1}^{n} \left(\xi_{ij}^* - \left(\xi_{ij}^*\right)_{mean}\right)^2, \xi_{ij} = \xi_{ij}^* w_j$$

Table 4: Weighted Normalized Decision matrix

Materials	MOE	YS	UTS	PR	D
Steels	0.093657833	0.14448224	0.090748678	0.076995186	0.088531
Aluminum and its alloys	0.075100231	0.118369224	0.081642653	0.072867887	0.077995
Titanium and its alloys	0.081405139	0.140073748	0.095168987	0.070900011	0.083038
Ceramics	0.118163222	0	0.099854703	0.102925058	0.094923
Carbon fibers	0.105910528	0	0.102786188	0.091265425	0.074526
Kevlar fibers	0.077460652	0	0.104275011	0.065335552	0.071512

MOE=Modulus of Elasticity (E) (GPa), YS=Yield stress (Y) (MPa), UTS=Ultimate Tensile Strength (UTS) (MPa), PR=Poisson's ratio (ν), D=Density (ρ)(kg/m3)

From Table 4, the ideal solution & negative ideal solution are computed by using eqns

$$A^+ = \{v_1^+, \dots \dots \dots, v_m^+\} = \{(max v_{ij} \backslash j \epsilon I'), (min v_{ij} \backslash j \epsilon I'')\}$$

$$A^- = \{v_1^-, \dots \dots \dots, v_m^-\} = \{(min v_{ij} \backslash j \epsilon I'), (max v_{ij} \backslash j \epsilon I'')\}$$

Table 5: The Ideal solution & Negative ideal solution

A^+	0.118163222	0.14448224	0.104275011	0.102925058	0.094923
A^-	0.075100231	0	0.081642653	0.065335552	0.071512

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By using Table 5, ideal solution (***D_i^+***), and the negative ideal solution (***D_i^-***) is computed using $D_i^+ = \sqrt{\sum_{j=1}^{m}(v_{ij} - v_j^+)^2}$, $D_i^- = \sqrt{\sum_{j=1}^{m}(v_{ij} - v_j^-)^2}$

Table 6: Ideal Solution matrix

Materials	MOE	YS	UTS	PR	D
Steels	0.000600514	0	0.000182962	0.000672358	4.09E-05
Aluminum and its alloys	0.001854421	0.00068189	0.000512224	0.000903434	0.000287
Titanium and its alloys	0.001351157	1.94348E-05	8.29197E-05	0.001025604	0.000141
Ceramics	0	0.020875118	1.95391E-05	0	0
Carbon fibers	0.000150129	0.020875118	2.2166E-06	0.000135947	0.000416
Kevlar fibers	0.001656699	0.020875118	0	0.001412971	0.000548

MOE=Modulus of Elasticity (E) (GPa), YS=Yield stress (Y) (MPa), UTS=Ultimate Tensile Strength (UTS) (MPa), PR=Poisson's ratio (ν), D=Density (ρ)(kg/m3)

Table 7: Negative Ideal Solution matrix

Materials	MOE	YS	UTS	PR	D
Steels	0.000344385	0.020875118	8.29197E-05	0.000135947	0.00029
Aluminum and its alloys	0	0.014011273	0	5.67361E-05	4.2E-05
Titanium and its alloys	3.97519E-05	0.019620655	0.000182962	3.09632E-05	0.000133
Ceramics	0.001854421	0	0.000331679	0.001412971	0.000548
Carbon fibers	0.000949274	0	0.000447049	0.000672358	9.09E-06
Kevlar fibers	5.57159E-06	0	0.000512224	0	0

MOE=Modulus of Elasticity (E) (GPa), YS=Yield stress (Y) (MPa), UTS=Ultimate Tensile Strength (UTS) (MPa), PR=Poisson's ratio (ν), D=Density (ρ)(kg/m3)

By using Table 6 &7, Calculation of Ranking score (***C_i*****) is done using Eqn. $\mathbf{C_i^* = D_i^+ / (D_i^+ + D_i^-) \quad i = 1, 2, \ldots n}$

Table 8: Ranking score (C_i*)

Materials	***C_i*****
Steels	0.792107
Aluminum and its alloys	0.645962
Titanium and its alloys	0.734268
Ceramics	0.308203
Carbon fibers	0.236815
Kevlar fibers	0.126941

From the Ranking score values the optimal value is finally determined such that the larger TOPSIS value indicates better quality. The order of that collected data is Steels, Titanium and its alloys, Aluminum and its alloys, Ceramics, Carbon fibers and Kevlar fibers.