Comparative analysis of Fuzzy MCDM methods for material selection in biomedical application

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Abstract:-

Material plays a vital role in an engineering design process. Selecting the appropriate material for a certain product is the vital task for engineering designer. In order to fulfil design requirement, the designer need to evaluate material alternatives by following a systematic selection. If the selection process is carried out haphazardly, there will be the risk of overlooking possible attractive materials. This risk can be reduced by implementing an efficient methodology. Hence, the aim of this paper is to develop a methodology, based on Fuzzy TOPSIS and sensitivity analysis, to select the appropriate material in biomedical application that is taken only as an illustrative example. Eleven candidate materials are evaluated, , to find the optimal material for a biomedical component "hip prosthesis", and nine evaluation criteria that called: tensile strength, corrosion resistance, fatigue strength, wear resistance, elastic modulus, tissue tolerance, specific gravity and cost are considered. Co_Cr alloys_Wrought alloy are found as the best material for hip prosthesis production. The results obtained are verified via a sensitivity analysis, and also compared with the existing methods to check the robustness of the proposed methodology.

Keywords: Material selection, Fuzzy Topsis, Sensitivity Analysis.

I. INTRODUCTION

Material selection is one of crucial function in the design process and development of products, and researchers recently have paid attracted attention to handle the material selection problems. An inappropriate selection may leads to increase the probability of the failure occurrence and also can negatively impact on product function, customer satisfaction and product life cycle. In contrast, an optimal selection could significantly enhance the product performance and reduce the cost that represent the goal of the optimum product design [12,13and 11]. The best material is the one having the highest or lowest value (Max/Min) when consider a single criteria, based on the objective of design requirement. In reality, select the optimal material from number of candidate alternatives is considered a multi criteria decision making (MCDM) problem. For this reason, the engineering designer requires not only the knowledge about the materials properties but also understanding of MCDM methods [13,15].Many research have been used MCDM techniques to select the optimal material for different engineering applications, in order to enhance the efficiency in design process and product development. For example, TOPSIS (technique for order performance by similarity to ideal solution) [15,5], VIKOR (VlseKriterijumskaOptimizacijaKomp romisnoResenje, means Multi-criteria optimization and Compromise Solution) [9], PROMETHEE (preference ranking organization method for enrichment evaluation) [4], ELECTRE (elimination and choice expressing the reality) [14], COPRAS-G [12] and COPRAS (complex proportional assessment) [3] are widely used in finding the best option from different material candidates.Unfortunately, the results of these methods are not accurate as it does not able to handle decision problem when the information ambiguous. For this reason, many researchers combined Fuzzy Logic concepts with MCDM techniques to overcome the above problem. The main characteristic of fuzzy logic is to handle any complicated problem and reflect the human thinking style [11, 6]. To the knowledge of the authors, a study in materials selection regarding to the application of bio-medical application is still not available in the literature.

In this paper, a new methodology is presented to assist the designer to make the right decision by selecting an appropriate material from set of alternatives. The methodology is built based on Fuzzy TOPSIS (FTOPSIS) and sensitivity analysis. FTOPSIS is applied to rank the candidate materials, and then sensitivity analysis is used to verify the results that obtained using FTOPSIS. The verified results is also compared with the existing methods to check the robustness of the methodology.

II. PROPOSED METHODOLOGY

In this paper, a comprehensive methodology is proposed using FTOPSIS and sensitivity analysis to final optimal material, from different alternatives for any sensitive components such as biomedical applications. The methodology consists three main phases: (*A*) problem description; (*B*) application of FTOPSIS; and (*C*) results analysis, as depicted in **Fig 1**. The goal of the proposed methodology is to find the optimal material based on multi-criteria for any bio-medical parts, such as a hip prosthesis.

A. Problem Description

The problem of material selection must be first described as a hierarchical structure which is built based on three elements to simplify the complexity of material selection problem. The first element is to define the goal "select an optimal material" for bio medical application based on multi-criteria decision-making. The second element is to specify the criteria that fulfil the overall goal such as corrosion resistance, fatigue strength, elastic modulus and tensile strength. The third element is to determine the candidate materials that could be fit to the specific application.

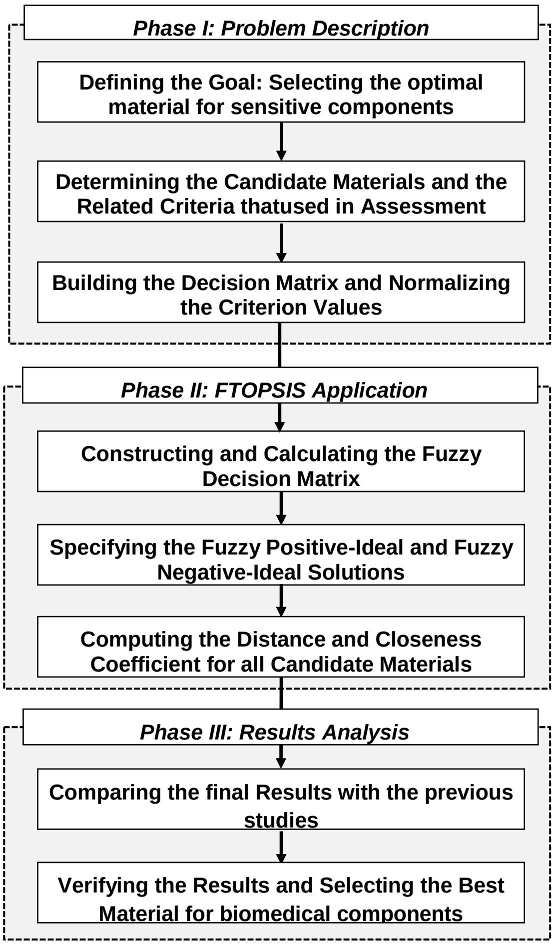

Fig.1 Proposed Methodology

B. Application of Fuzzy TOPSIS

Fuzzy TOPSIS (FTOPSIS) can be employed to determine the optimal material from a number of candidate materials by following six steps, as summarized below:

Step 1: Establish the $m \times n$fuzzy-decision matrix ($\tilde{D}$). C_n denote the criteria, and M_m denote the possible alternatives (Materials).

$$\tilde{D} = \begin{matrix} \\ M_1 \\ M_2 \\ \vdots \\ M_m \end{matrix} \begin{matrix} C_1 \; C_2 \; \cdots \; C_n \\ \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \end{matrix} \quad (1)$$

Step 2: Normalize the fuzzy decision matrix to convert the different measurement scales for criteria into a similar scale. The new matrix ($\tilde{R}$) is represented as:

$$\tilde{R} = [\tilde{r}_{ij}]_{m\times n}, i = 1,2 \dots m; \; j = 1,2,\dots n \quad (2)$$

The normalization process for both benefit (B) and cost (C) criteria are computed consequently as follows:

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{n_{ij}}, \frac{m_{ij}}{n_{ij}}, \frac{n_{ij}}{n_{ij}}\right), j\epsilon B \quad (3)$$

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{l_{ij}}, \frac{m_{ij}}{l_{ij}}, \frac{n_{ij}}{l_{ij}}\right), j\epsilon C \quad (4)$$

Steps 3: Calculated the weighted decision matrix by multiplying the w_j (weight for criteria j) with the values of each column in the matrix ($\tilde{r}_{ij}$). The $\tilde{V}$ is defined as:

$$\tilde{V} = [\tilde{r}_{ij} \times \tilde{w}_{ij}]_{m\times n} \quad (5)$$

Steps 4: Specify the positive (FPIS) and negative (FNIS) ideal solution. The FPIS denoted by (aspiration levels A^+) and the FNIS denoted by the (worst levelsA^-). A^+ and A^-represented as shown below:

$$A^+ = \{(max_i v_{ij} | i = 1,2,\dots,m)\} \quad (6)$$

$$A^{-} = \{(min_i v_{ij} | i = 1, 2, \dots, m)\} (7)$$

*Step 5:*Compute the distance of all alternatives from $A^{+}$and A^{-} as follows:

$$D^{*} = \sqrt{\frac{1}{3}[(1-l_1)^2 + (1-m_1)^2 + (1-n_1)^2]} (8)$$

$$D^{-} = \sqrt{\frac{1}{3}[(0-l_1)^2 + (0-m_1)^2 + (0-n_1)^2]} (9)$$

Step 6: Compute the closeness coefficient(CC_j) factor for each possible alternatives (Materials). The alternative that have highest CC_j will be the optimal candidate material. CC_jCan be computed as follows:

$$CC_j = \frac{D_j^{-}}{D_j^{-} + D_j^{*}} , \quad j = 1, \dots, n \quad (10)$$

C. Analysis of the Results

Analysis the final results are considering the key element to check whether these results are stable or not. A sensitivity analysis is applied in this paper to analyse the results obtained by implement FTOPSIS, to check the effect of the criteria weights on the final ranking, and to also investigate if any changes in the criteria weights could be lead to modification in the decision outcome.

According to related research, sensitivity analysis can be achieved by increasing/decreasing the weights of each criterion and the total summation of all criteria value weights must equal to one.

I. Hypothetical Case Study

A hypothetical case application “hip prosthesis” is considered that includes three element: femoral component, acetabular cup, and acetabular interface as shown in **Fig 2**.

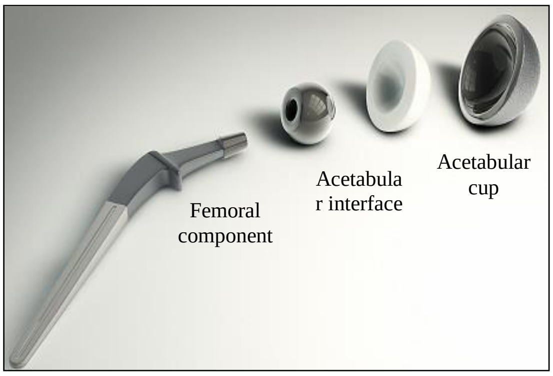

Fig.2 Hip prosthesis design

A hip prosthesis, a rigid pin, is imbedded in the shaft of the femur replaces the femoral head, and while the pelvic socket is substituted by a cup that is fixed to the ilium. In this work, material for pin has been considered with multi criteria such as corrosion resistance, fatigue strength, wear resistance and cost. The possible materials for pin and their criteria are shown in TABLE I. In this application, the most promising values for all above criteria are determined respectively as follow (10, 10, 985, 600, 10, 10, 14, 2.1, and 1.1). From these results, for single criterion, it can be noticed that the best material is the one having the highest or smallest value based on objective of design (Max or Min). Nevertheless, for multi-criteria, it can be seen that the optimal material is not as straightforward as that of single-criteria, due to a desired value for one criteria response may correspond to an inappropriate value for another criteria. The conflicting reveal that selecting an optimal material forhip prosthesis is a MCDM problem.

III. Results And Discussion

The candidate materials and the nominated criteria is established as a decision table. This table called a decision table that contains the values of each criterion with respect to the suggested materials. In the illustrative case application, the first step is to normalize values for each criterion, as shown in **Table I**, to range between 0-1. The next step is to apply the FTOPSIS as described above. First, built the decision matrix by evaluate the alternatives (candidate materials) with respect to nine as shown TABLE II. Second, normalisation the values for the matrix and convert it to range between [0, 1]. Third, establish a weighted decision matrix which can be obtained using the Equation (5). Fourth, determine the *FPIS*-A^+ and *FNIS*-A^- through Equations 6 and 7. Fifth, compute(D_i^+, D_i^-) for all alternative from *FPIS* and *FNIS* using Equations 8 and 9. Finally, compute CC_j for each material using Equation 10. The final rank are shown in TABLE III and depicted in Fig 3.

According to these results, it can be conclude that the M_6 (Co_Cr alloys_Wrought alloy (2)) is the optimal material for a hip prosthesis, with a *(*Closeness Coefficient*)* value of 0.0810. The weakness material is M_{10} (Composites-Epoxy-63% carbon) with a CC_j value of 0.0280. Therefore, the order from optimal material to the worst one is: $M_6 > M_8 > M_5 > M_7 > M_4 > M_2 > M_1 > M_3 > M_9 > M_{11} > M_{10} > M_5$. The results obtained by FTOPSIS must be verify, this can be done using sensitivity analysis by changing the criterion weight (increase/decrease) and the criteria weights, as a value, must equal to one. To conduct this analysis, four scenarios are suggested in this study (Case 1, Case 2 … Case 4) as shown in **Table IV**.

The results of sensitivity analysis test are plotted as shown Fig 3, to show the verification of the final results. According to this Figure, it can be seen that nearly all of the changing the criterion weight do not have any significant effect on the decision. Consequently, the analysis test reflects the robustness of the results that obtained by proposed methodology. The final results is also compared with the existing methodologies that reported by Jahan et al. [10] and Farag [8], as shown in **Table III.**

IV. Conclusions

This paper is devoted to the application of the proposed methodology, to verify the capability of suggested methodology to tackle the problems of material selection. The proposed methodology can applied in different engineering fields, not only for bio-medical applications such as “hip prosthesis” as mentioned earlier, but also to find the optimal alternative for a certain application. The sensitivity analysis results showed that the proposed methodology has significant features. For example, it has the ability to examine the candidate materials for different applications such as biomedical component and also it finds the optimal material based on the conflicting multi-criteria. The final ranking, using the proposed methodology, were compared with reported ranking by Jahan et al. [10] and Farag [8]. The comparison showed that the best and poorest alternative materials keep on in the same level. For this reason, the proposed methodology is applicable to implement in material selection issue and also is not limited to the application of biomedical material selection. Moreover, the methodology can be efficiently useful to different types of engineering applications. A further study could be combining a Fuzzy TOPSIS with Fuzzy AHP to find the optimal material. The FAHP can be used to specify the weights for selected criteria; and the FTOPSIS is applied to rank the feasible alternatives and make the final decision.

TABLE I. DECISION MATRIX FOR HIP JOINT PROSTHESIS MATERIAL SELECTION

Objectives of design / Criteria	Max Tissue Tolerance	Max Corrosion Resistance	Max Tensile Strength	Max Fatigue Strength	Max Relative Toughness	Max Relative Wear Resistance	Target Elastic Modulus	Target Specific Gravity	Min Cost
Stainless steels 316	10.0	7.00	517	350	8.00	8.00	200	8.00	1.00
Stainless steels 317	9.00	7.00	630	415	10.0	8.5	200	8.00	1.10
Stainless steels 321	9.00	7.00	610	410	10.0	8.00	200	7.90	1.10
Stainless steels 347	9.00	7.00	650	430	10.0	8.40	200	8.00	1.20
Co_Cr alloys_Cast alloy (1)	10.0	9.00	655	425	2.00	10.0	238	8.30	3.70
Co_Cr alloys_Wrought alloy (2)	10.0	9.00	896	600	10.0	10.0	242	9.10	4.00
Unalloyed titanium	8.00	10.0	550	315	7.00	8.00	110	4.50	1.70
Ti_6Al_4V	8.00	10.0	985	490	7.00	8.30	124	4.40	1.90
Composites - Epoxy-70% glass	7.00	7.00	680	200	3.00	7.00	22.0	2.10	3.00
Composites - Epoxy-63% carbon	7.00	7.00	560	170	3.00	7.50	56.0	1.60	100
Composites - Epoxy-62% aramid	7.00	7.00	430	130	3.00	7.50	29.0	1.40	5.00

TABLE II. FUZZY DECISION MATRIX FOR DIFFERENT MATERIALS WITH THEIR CRITERIA

Material No.	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
M_1	(0.8, 1.0, 1.0)	(0.0, 0.0, 0.2)	(0.1, 0.2, 0.3)	(0.4, 0.5, 0.6)	(0.7, 0.8, 0.9)	(0.2, 0.3, 0.4)	(0.1, 0.2, 0.3)	(0.1, 0.2, 0.3)	(0.8, 1.0, 1.0)
M_2	(0.6, 0.7, 0.8)	(0.0, 0.0, 0.2)	(0.3, 0.4, 0.5)	(0.5, 0.6, 0.7)	(0.8, 1.0, 1.0)	(0.4, 0.5, 0.6)	(0.1, 0.2, 0.3)	(0.1, 0.2, 0.3)	(0.8, 1.0, 1.0)
M_3	(0.6, 0.7, 0.8)	(0.0, 0.0, 0.2)	(0.2, 0.3, 0.4)	(0.5, 0.6, 0.7)	(0.8, 1.0, 1.0)	(0.2, 0.3, 0.4)	(0.1, 0.2, 0.3)	(0.1, 0.2, 0.3)	(0.8, 1.0, 1.0)
M_4	(0.6, 0.7, 0.8)	(0.0, 0.0, 0.2)	(0.3, 0.4, 0.5)	(0.5, 0.6, 0.7)	(0.8, 1.0, 1.0)	(0.4, 0.5, 0.6)	(0.1, 0.2, 0.3)	(0.1, 0.2, 0.3)	(0.8, 1.0, 1.0)
M_5	(0.8, 1.0, 1.0)	(0.6, 0.7, 0.8)	(0.3, 0.4, 0.5)	(0.5, 0.6, 0.7)	(0.0, 0.0, 0.2)	(0.8, 1.0, 1.0)	(0.0, 0.0, 0.2)	(0.1, 0.2, 0.3)	(0.6, 0.7, 0.8)
M_6	(0.8, 1.0, 1.0)	(0.6, 0.7, 0.8)	(0.7, 0.8, 0.9)	(0.8, 1.0, 1.0)	(0.8, 1.0, 1.0)	(0.8, 1.0, 1.0)	(0.0, 0.0, 0.2)	(0.0, 0.0, 0.2)	(0.6, 0.7, 0.8)
M_7	(0.2, 0.3, 0.4)	(0.8, 1.0, 1.0)	(0.1, 0.2, 0.3)	(0.3, 0.4, 0.5)	(0.5, 0.6, 0.7)	(0.2, 0.3, 0.4)	(0.5, 0.6, 0.7)	(0.6, 0.7, 0.8)	(0.6, 0.7, 0.8)
M_8	(0.2, 0.3, 0.4)	(0.8, 1.0, 1.0)	(0.8, 1.0, 1.0)	(0.7, 0.8, 0.9)	(0.5, 0.6, 0.7)	(0.3, 0.4, 0.5)	(0.4, 0.5, 0.6)	(0.6, 0.7, 0.8)	(0.8, 1.0, 1.0)

M9	(0.0, 0.0, 0.2)	(0.0, 0.0, 0.2)	(0.4, 0.5, 0.6)	(0.1, 0.2, 0.3)	(0.0, 0.0, 0.2)	(0.0, 0.0, 0.2)	(0.8, 1.0, 1.0)	(0.8, 1.0, 1.0)	(0.7, 0.8, 0.9)
M10	(0.0, 0.0, 0.2)	(0.0, 0.0, 0.2)	(0.1, 0.2, 0.3)	(0.0, 0.0, 0.2)	(0.0, 0.0, 0.2)	(0.1, 0.2, 0.3)	(0.7, 0.8, 0.9)	(0.8, 1.0, 1.0)	(0.0, 0.0, 0.2)
M11	(0.0, 0.0, 0.2)	(0.0, 0.0, 0.2)	(0.0, 0.0, 0.2)	(0.0, 0.0, 0.2)	(0.0, 0.0, 0.2)	(0.1, 0.2, 0.3)	(0.8, 1.0, 1.0)	(0.8, 1.0, 1.0)	(0.5, 0.6, 0.7)
Weight	0.20	0.20	0.08	0.12	0.08	0.08	0.08	0.08	0.08

$$\boldsymbol{D_1^*} = \sqrt{\frac{1}{3}[(1-0.160)^2+(1-0.200)^2+(1-0.200)^2]} + \sqrt{\frac{1}{3}[(1-0.000)^2+(1-0.000)^2+(1-0.040)^2]} + \sqrt{\frac{1}{3}[(1-0.008)^2+(1-0.012)^2+(1-0.024)^2]}$$

$$+ \sqrt{\frac{1}{3}[(1-0.048)^2+(1-0.060)^2+(1-0.072)^2]} + \sqrt{\frac{1}{3}[(1-0.056)^2+(1-0.064)^2+(1-0.072)^2]} + \sqrt{\frac{1}{3}[(1-0.016)^2+(1-0.024)^2+(1-0.032)^2]}$$

$$+ \sqrt{\frac{1}{3}[(1-0.008)^2+(1-0.016)^2+(1-0.024)^2]} + \sqrt{\frac{1}{3}[(1-0.008)^2+(1-0.016)^2+(1-0.024)^2]} + \sqrt{\frac{1}{3}[(1-0.064)^2+(1-0.080)^2+(1-0.080)^2]}$$

$$= \mathbf{8.531}$$

$\boldsymbol{D_1^-}$ =**0.487**

$$\boldsymbol{CC_j} = \frac{\boldsymbol{D_1^-}}{\boldsymbol{D_1^*} + \boldsymbol{D_1^-}} = \mathbf{0.0540}$$

TABLE III. RESULTS OF PROPOSED METHODOLOGY AND COMPARISON WITH EXISTING METHODOLOGYES.

Materials	D_j^+	D_j^-	CC_j	**Proposed Methodology**	**Reported rank by Jahanet al. [10]**	**Reported rank by Farag [8]**
Stainless steels 316	8.531	0.487	0.0540	7	5	4
Stainless steels 317	8.523	0.494	0.0547	6	7	6
Stainless steels 321	8.545	0.472	0.0523	8	8	7
Stainless steels 347	8.522	0.494	0.0548	5	6	5
Co_Cr alloys_Cast alloy (1)	8.412	0.601	0.0667	3	2	9

Co_Cr alloys_Wrought alloy (2)	8.282	0.730	0.0810	1	1	2
Unalloyed titanium	8.439	0.570	0.0632	4	4	3
Ti_6Al_4V	8.330	0.678	0.0752	2	3	1
Composites - Epoxy-70% glass	8.691	0.341	0.0378	9	9	8
Composites - Epoxy-63% carbon	8.786	0.253	0.0280	11	11	11
Composites - Epoxy-62% aramid	8.742	0.294	0.0326	10	10	10

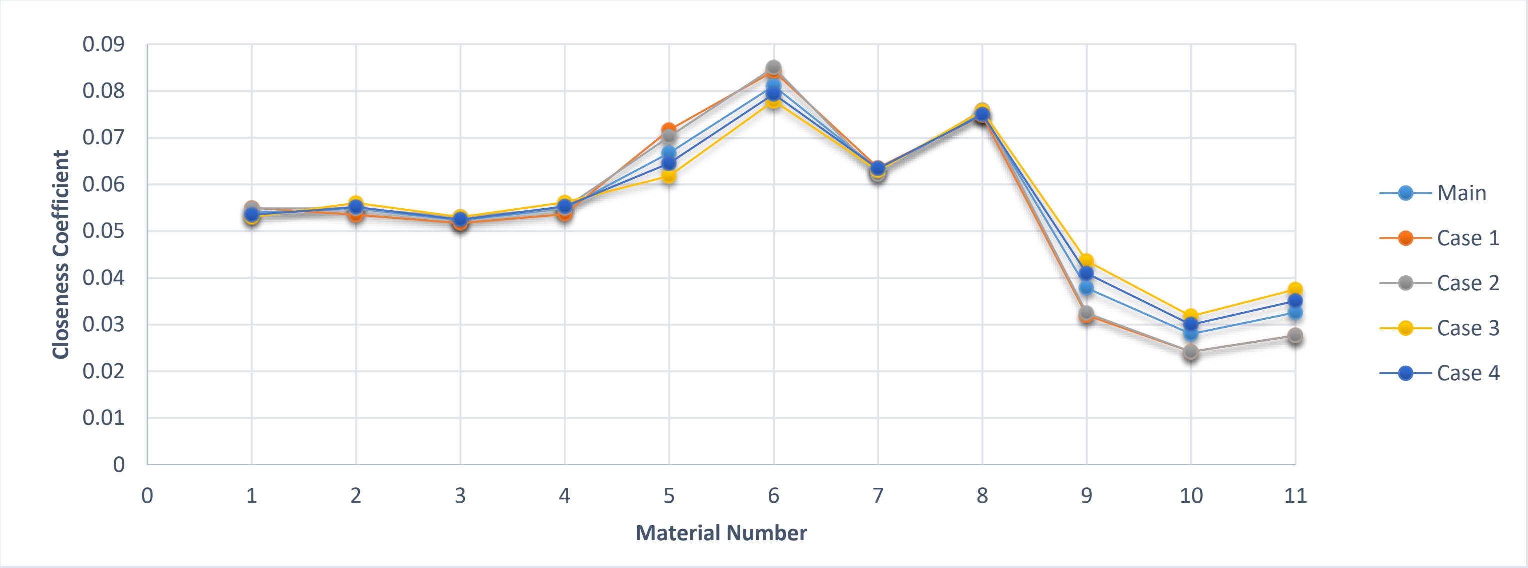

Fig.3.Sensitivity Analysis

TABLE IV. EXCHANGE CRITERION'S WEIGHT

	Main	Case1	Case2	Case3	Case4
Criteria #1	0.20	0.25	0.22	0.15	0.18
Criteria #2	0.20	0.25	0.22	0.15	0.18
Criteria #3	0.08	0.06	0.06	0.10	0.09
Criteria #4	0.12	0.14	0.20	0.10	0.10
Criteria #5	0.08	0.06	0.06	0.10	0.09
Criteria #6	0.08	0.06	0.06	0.10	0.09
Criteria #7	0.08	0.06	0.06	0.10	0.09
Criteria #8	0.08	0.06	0.06	0.10	0.09
Criteria #9	0.08	0.06	0.06	0.10	0.09

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تحليل مقارن لطرق المنطق الضبابي لاختيار مادة لاحد تطبيقات الطب الحيوي

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الجامعة التكنولوجية

الخلاصة:-
تلعب المادة دوراً حيويا في عملية التصميم الهندسي حيث ان اختيار المادة المناسبة لمنتج معين هو احدالمهام الاساسية للمصمم. لذا من ومن أجل تلبية متطلبات التصميم المطلوب، يحتاج المصمم انيقييم المواد الهندسية المتاحة عن طريق تطبيق منهجية فعالة كون إذا تمت عملية الاختيار بشكل عشوائي سيكون هناك خطر محتمل يتمثل بعدم اختيار المادة الاكثر ملائمة. وبالتالي،فإن الهدف من هذا البحث هووضع منهجية تعتمد على احد طرق المنطق الضبابي (Fuzzy TOPSIS and) وتحليل الحساسية (sensitivity analysis)،لتحديد المادة المناسبة لاحد تطبيقات الطب الحيوي التيتم أخذها فقط كمثال توضيحي.تم تقييم أحدعشرمادة مرشحة ،لتحديد امثل مادة لاحد تطبيقات الطب الحيوي "hip prosthesis" كذلك تم تحديد تسعة معاييرتقييم: قوة الشد، مقاومة التآكل ، معامل المرونة والتكلفة وغيرها. تم الاستنتاج بأن سبائك (Co_Cr alloys_Wrought) هي أفضل مادة لإنتاج "hip prosthesis". كذلك تم تطبيقت تحليل الحساسية، وأيضا مقارنة النتائج مع الطرق الحالية للتحقق من متانة المنهجية المقترحة.