Selection of Suitable Biomaterial for Prosthetic- Plate using Multi Criteria Decision Analysis

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ABSTRACT

Multiple-criteria decision analysis (MCDA) consist of a finite number of alternatives,known in the beginning of the solution process. Objective of this paper is to apply the various MCDA methodologies to obtain the best suitable bio-material for prosthetic plate by using multiple criteria belongs to material properties, resultant stresses and cost. Resultant of multi objectives material design optimization method is to obtain maximum numerical values in the mode of ranking of five different materials as Alumina (Al_2o_3), Nylon6/6, Poly-methyl methacrylate PMMA, Stainless steel SS316L &Titanium alloy Ti4-Al6-V. MCDA is also recommended the highest ranking material for prosthetic plate for implanting with fractured femur human bone in the field of healthcare.

Keywords: *Multi-criteria, Multi-decision, Bio-materials, Ranking.*

1. INTRODUCTION

It is the process of selecting two or more subject of action. It is understood that it should not always be an accurate decision among the various choices. Multiple-criteria evaluation technique consist of a finite number of alternatives, known in the beginning of the solution process. In Multiple- criteria design making the alternatives are not known. Solutions can be found by solving a mathematical model. The number of alternatives is either infinite or not countable (when some variables are continuous) or typically very large if countable (when all variables are discrete) [1]. But both kind of problems are considered as a subclasses of Multi Criteria Decision Making problems. The MCDM problems can also be classified into two major classes with respect to the way the weights of the alternatives are determined: Compensatory and Outranking Decision Making.

2. OBJECTIVES

Objectives of Multi Criteria Decision Analysis to understanding of the

- Ranking method of objectives materials with cost, benefit and target design criteria
- Concept of multi-objective material design optimization
- Selection of best suitable material and geometrical optimization process
- Advantages of quality function deployment (QFD) in the materials selection process
- Ranking of materials and design scenarios with data uncertainty in design attributes
- Importance of materials selection strategy for multiple components
- Application of Pareto front diagram in material selection
- Use of group discussion-making by a team of engineers and designers evaluation qualitative material selection process.

3. TYPES OF MCDA CRITERIA

Each index or criterion combines a defined set of properties as like tensile properties, elastic modulus, density and cost [2].

Table.1 Types of MCDA [4] criteria

Types of Criteria			
Criterion-1	Criterion-2	Criterion-3	Criterion-4
Individual Material Properties	Indices made by combination of individual material properties	Indices made by combination of material properties and geometry	Nontechnical criteria as like cost or availability for long term

They are used to evaluate candidate materials for a specific application as shown in Table.1.

3.1 INDIVIDUAL MATERIAL PROPERTIES OF PROSTHETIC PLATE

Here Table.2 shows the sensitivity of the simple performance index on its constituent properties for five different prosthetic material of plate. It can be seen that from column one that modulus of elasticity is maximum of nylon6/6 and from the second column, density is minimum of PMMA so respectively both materials has the best initial technical properties while, the cost of alumina is minimum but performance index suggest, M_1 by including the cost of material suggests that nylon 6/6 is the best suitable material because of the maximum index value. But once again we cannot suggest the alumina or nylon due to its toxic properties and reaction with the human body. Further this method is not suitable for screening of any biomaterial according the simple performance index value by initial technical material properties and cost. Finally it is seen that selection of material is limited to stainless steel and titanium which is the latest applicable trend of using prosthetic plate foe supporting the fractured femur bone. Performance Index [3] according to the material properties is the ratio of young modulus to the multiplication of density and cost per kg.

Performance Index = E/(ρ x C) ………………(1)

1. Alumina $[M_1] = (E_{Al})/(\rho_{Al} x C_{Al})$

= 240/(8500x45)

= $6.274x10^{-4}$…………………….. (2)

2. Nylon $[M_2] = (E_{NI})/(\rho_{NI} x\ C_{NI})$

= 300/(3720x110)

= $7.33x10^{-4}$ ………………………… (3)

3. PMMA$[M_3] = (E_{PMMA})/(\rho_{PMMA} x\ C_{PMMA})$

= 220/(1180x200)

= $9.322x10^{-4}$…………………….... (4)

4. SS316L $[M_4] =(E_{SS})/(\rho_{SS} x\ C_{SS})$

= 193/(7750x250)

= $99.61x10^{-4}$ …………………….. (5)

5. Ti-6Al-4V $[M_5] = (E_{TiAl})/(\rho_{TiAl} x\ C_{TiAl})$

=120/ (4500x2000) =$13.33x10^{-4}$(6)

Table.2 Effect of performance index on the selected material: Importance of weighting

Objective Material	Elastic Modul -us (E) GPa [Max]	Densi-ty (ρ) Mg/m^3 [Min]	Cost (C)Rs/ kg [Min]	M_i=(E) /(ρc) $[10^{-4}]$ [Max]	Rank -ing of Obje-ctive Mate -rial
Al_2o_3	240	8500	45	6.274	5
Nylon6/6	300	3720	110	7.331	4
PMMA	220	1180	200	9.322	3
SS316L	193	7750	250	99.6	1
Ti-6Al-4V	120	4500	2000	13.33	2

3.2 INDICES MADE BY COMBINATION BY INDIVIDUAL PROSTHETIC PLATE MATERIAL

Furthermore, performance indices can be affected by the mathematical formulation used. Table.3 and Table.4 compares a simple ratio based performance index with subtraction based index. It is cleared that comparing stress and tensile strength of five different biomaterials, that the von-mises stress is maximum in nylon and minimum in the titanium alloy at the apply load of 750N in comparison of other materials. In the initial healing process stress should be minimum and the tensile strength is maximum of titanium alloy which one is the most preferable material in recent trends. The maximum value of ratio of (B/A) and value of difference (B-A) makes titanium alloy is best suitable material for prosthetic plate. On the other side alumina is the worst case material for selecting the same for supporting the femur bone.Performance Index according to the strength of materials is the ratio of tensile strength to the maximum von-mises stress of the particular material by the following formula

Performance Index PI1 = Tensile Strength (B)/Max Von-Mises stress (A)

= B/A ……………….. (7)

Performance Index PI_2 = Tensile Strength – Maximum Von-Mises Stress

= B – A ……………….. (8)

1. Alumina $Al_2O_3 PI_{AL1} = \sigma_{tAL}/\sigma_{vonAL}$

= 290/476.12

= 0.6208 …………………(9)

$PI_{AL2} = \sigma_{Tal} - \sigma_{vonAL}$

= 290 – 476.12
= -177.12 ……………….(10)

2. Nylon6/6 (polymer)
$PI_{NL1} = \sigma_{tNL} / \sigma_{vonNL}$
= 195/601.3
= 0.6208 ……………………..(11)
$PI_{NL2} = \sigma_{tNL} - \sigma_{vonNL}$
= 195 – 601.3
=-406.3…………………….... (12)
3. PMMA $PI_{PMMA1} = \sigma_{tPMMA} / \sigma_{vonPMMA}$
= 79/59.488
= 1.32………………………...(13)
$PI_{PMMA2} = \sigma_{tPMMA} - \sigma_{vonPMMA}$
= 79 – 59.488
= 19.512 ……………………...(14)
4.SS316L $PI_{SS1} = \sigma_{tSS} / \sigma_{vonSS}$
= 485/405.71
= 1.195 …………………………(15)
$PI_{SS2} = \sigma_{tSS} - \sigma_{vonSS}$
= 485-405.71
= 79.29 …………………………..(16)
5.Ti-6Al-4V $PI_{TiAL1} = \sigma_{tTiAL} / \sigma_{vonTiAL}$
= 993/332.27
= 2.98 ………………………(17)
$PI_{TiAL2} = \sigma_{tTiAL} - \sigma_{vonTiAL}$
= 993-332.27
= 660.63 ………………………(18)

Table.3 Effect of Performance Index formula on material ranking

Objective Material	Maximum Von-mises Stress $\sigma_{vonmises}$(MPa) A	Tensile Strength σ_t (MPa) B	B/A	B-A	Ran-king of Obj-ecti-ve Mat-erial
Al_2O_3	467.12	290	0.62	-177.12	5
Nylon6/6	601.3	195	0.32	-406.3	4
PMMA	59.488	79	1.32	19.51	3
SS316L	405.71	485	1.19	79.29	2
Ti-6Al-4V	332.27	993	2.98	660.73	1

3.3 INDICES MADE BY COMBINATION OF PROSTHETIC PLATE MATERIAL PROPERTIES AND GEOMETRY

For designing the prosthetic plate the following properties are very crucial as like maximum stress, tensile strength, fracture toughness and density as shon in Tbale.4. The cost is considered from India Mart website which is vary time to time. The relevant material performance indices M_1, M_2 and M_3 combining the material properties are shown along with the cost again for convenience in Table.5. The performance indices have different units and allow to directly compare to be made, each performance index has been normalized by expressing its value relative to its largest value. The last column combines the weighted relative performance as an overall rating for each material. The overall rating formula has allocated different weightings to the relative performance indices and placed in sheet to check designer the sensitivity of result. If we compares the overall rating in the last column so titanium alloy has become best suitable material as compare to other material by considering the strength and cost. It is also observed that individual indexes are different according to different performance indices [7].

Table.4 Data for material used in fractured femur bone prosthetic plate

Objective Material	Maximum Von-mises Stress (MPa) at 750N Static Load [$\sigma_{vonmises}$]	Tensile Strength (MPa)	Fract-ureTough-hness K_{IC} (MPa)	Density (ρ) Mg/m^3	Cost (C) $/kg
Al_2O_3	467.12	290	35	8.50	0.69
Nylon6/6	601.3	195	58	3.72	1.69
PMMA	59.488	79	46	1.18	3.076
SS316L	405.71	485	98	7.75	3.84
Ti-6Al-4V	332.27	993	62	4.50	30.76

Overall absolute rating of material = M

= $[4M_1+2M_2+3M_3 + (1-C)]/10$ ………. (19)

Where M_1 = ratio of von-mises stress to the density of material

$= \sigma_v/\rho$ ………. ……………………………………(20)

M_2 = ratio of ^1/3 young modulus to the density of material

$= (E)^{1/3} / \rho$ ……………………………….............. (21)

M_3 = square of ratio of stress intensity factor to the von mises stress of the material

$= [K_{IC} /\sigma_v]^2$ ……………………………………… (22)

C = cost of the material per kg (Rs) ……………… (23)

Overall rating for

1. Alumina Al_2O_3

$M_{AL} = [4x(\sigma_{vAL}/\rho_{AL})+2x(E_{AL}^{1/3} /\rho_{AL})+3x(K_{ICAL}/\sigma_{Val})^2 +(1-C_{AL})]/10$ …………………………………….. (24)

$=[4x(467.12/8.50)+2x(240^{1/3}/8.50)+3x(35/467.12)^2+(1 -0.69)]/10$

= 22.15 ……………………………………………(25)

2. Nylon6/6

$M_{NL} = [4x(\sigma_{vNL}/\rho_{NL})+2x(E_{NL}^{1/3} /\rho_{NL})+3x(K_{ICNL}/\sigma_{Vnl})^2 +(1-C_{NL})]/10$ …………………………………….. (26)

$= [4x(601.3/3.72)+2x(300^{1/3}/3.72)+3x(58/601.3)^2 +(1-1.69)]/10$

= 64.99 ……………………………………… (27)

3. PMMA

$M_{PMMA}=[4x(\sigma_{vPMMA}/\rho_{PMMA})+2x(E_{PMMA}^{1/3}/\rho_{PMMA})+3x(K_{ICPMMA}/\sigma_{VPMMA})^2+(1-C_{PMMA})]/10$…………………. (28)

$= [4x(59.48/1.18)+2x(220^{1/3}/1.18)+3x(46/59.48)^2 +(1-1.18)]/10$ = 21.327 ………………………………..(29)

4.SS316L

$M_{SS} = [4x(\sigma_{vSS}/\rho_{SS})+2x(E_{SS}^{1/3} /\rho_{SS})+3x(K_{ICSS}/\sigma_{Vss})^2 +(1-C_{SS})]/10$ ……………………………………... (30)

$= [4x(405.71/7.75)+2x(193^{1/3}/7.75)+3x(98/405.71)^2 +(1-3.84)]/10$

= 20.81 ……………………………………….. (31)

5. Ti-6Al-4V

$M_{Ti} = [4x(\sigma_{vTi}/\rho_{Ti})+2x(E_{Ti}^{1/3} /\rho_{Ti})+3x(K_{ICTi}/\sigma_{Vti})^2 +(1-C_{Ti})]/10$ …………………………………………... (32)

$= [4x(332.27/4.5)+2x(120^{1/3}/4.5)+3x(62/332.27)^2 +(1-30.76)]/10$

=26.78 ……………………………………………….(33)

Table.5 Overall rating for the material used

Objective Material	M_1 (σ/ρ)	M_2 $(E)^{1/3} / \rho$	M_3 $[K_{IC} / \sigma]^2$	1-C	Overall Rating M	Ranking of Objective Material
Al_2O_3	219.82	1.43	0.016	0.31	22.15	3
Nylon6/6	646.23	3.53	0.027	-0.69	64.99	1
PMMA	201.62	10.04	1.79	-0.18	21.32	4
SS316L	209.40	1.46	0.175	-2.84	20.81	5
Ti-6Al-4V	295.35	2.15	0.104	-29.76	26.78	2

4. RESULTS AND DISCUSSIONS

It is observed from the first technique as shown in table.2 that SS316L is secured first rank and Ti4Al6V second rank by considering only individual material properties.

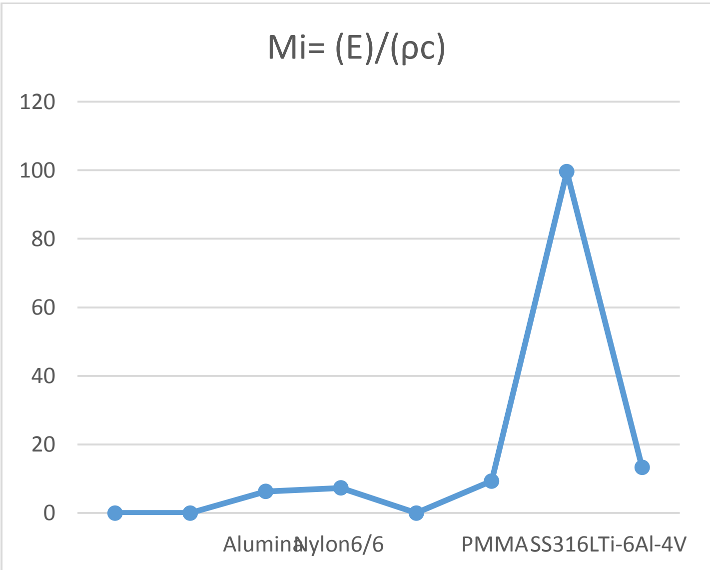

Fig.1 Performance index graphical representation of individual material

In second technique of MCDA, Ti4Al6V is secured first rank rather than SS316L got second position by evaluating performance index, dividing and subtraction ofinitial tensile strength and resultant von-mises strength.

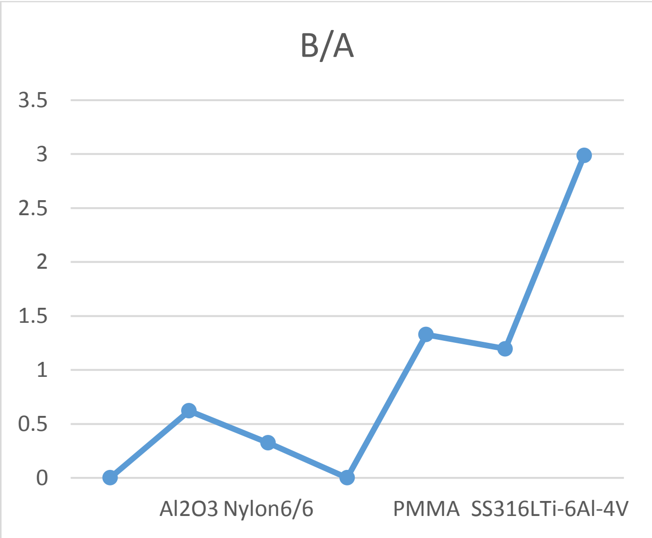

Fig.2 Graphical representation of performance index B/A of individual material

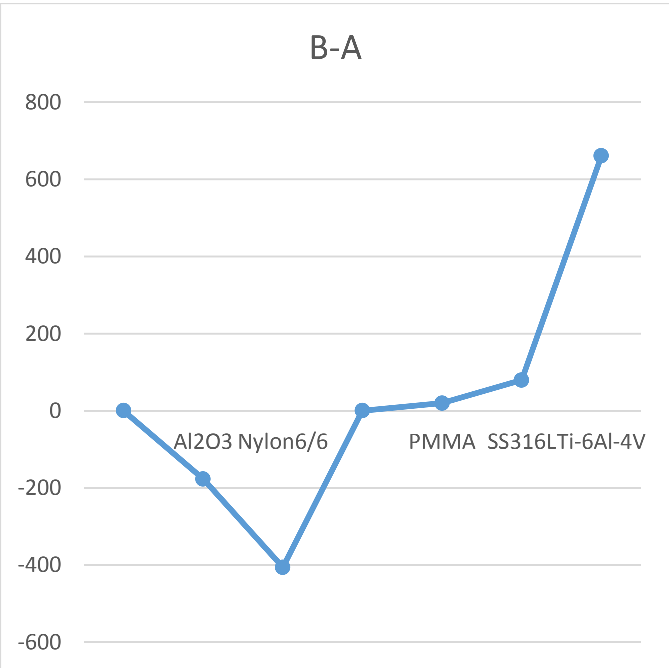

Fig.3 Graphical representation of performance index (B-A) of individual material

In third criteria, Nylon6/6 secured overall first ranking followed by Ti4Al6V got second position by considering of individual geometrical properties, strength criterion and cost for calculating of overall ratings of individual material.

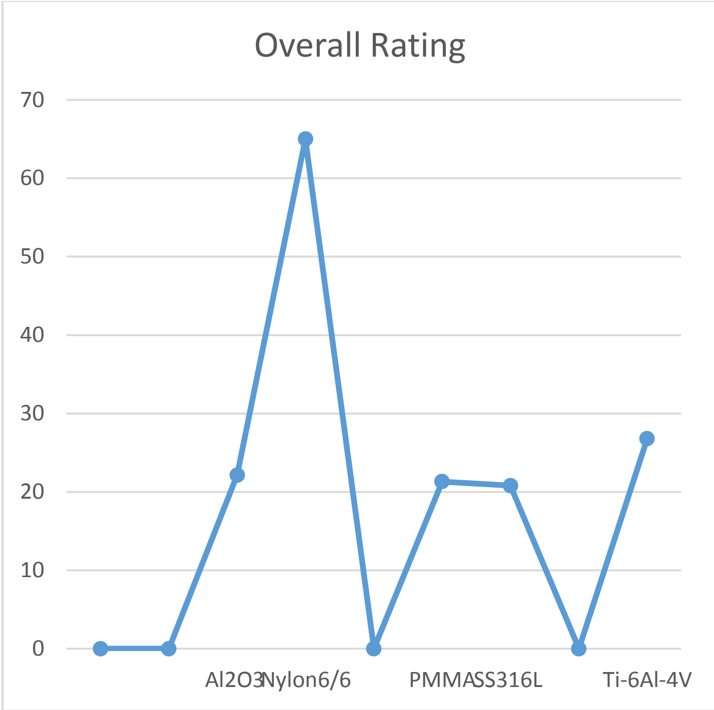

Fig.4 Overall rating performance index of individual material

5. CONCLUSION

Multiple-criteria decision analysis (MCDA) consist of a finite number of alternatives, known in the beginning of the solution process.The results from MCDA should not take as a final decision but the MCDA model should be used to explore the uncertainty in the decision problem. In this paper is to apply the various MCDA methodologies to obtain the best suitable bio-material for prosthetic plate by using multiple criteria belongs to material properties, resultant stresses and cost. It is observed that among of using all three techniques, SS316L as well as Ti6AL4V would be recommended in consideration of more strength requirement rather than the cost consideration. On the other hand where only strength is the major criterion, Ti6Al4V would like to recommend rather than SS316L by neglecting the cost consideration in the automotive [5], aeronautical and fractured human bone implantation. In a case of material cost and availability criterion would like to preferable than PMMA could be a first choice of user. The MCDA is the appropriate evidence before making their final decision.

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