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Selection of Best Bio-Ceramic Composite Material for Orthopedic Implant of Bones Using Grey Relational Analysis

Pratapsinh K Desai[1], Dr. Jahangir A.Tamboli[2],Dr. Hanmantaraju H G[3]
[1] Lecturer Selection Grade Institiute Of Civil And Rural Engineering, Gargoti,Kolhapur
[2] Principal, Nanasaheb Mahadik College Of Engineering.Pethnaka,Islampur,Sangli
Corresponding auther: Pratapsinh K Desai

***Abstract**: Metallic Biomaterials Are Widely Used For The Fabrication Of Surgical Implants Because Of Their High Strength And Resistance To Fracture. Metallic Biomaterials Are Suitable For Many Surgical Implants Because Of Their Excellent Mechanical Properties. Most Of Metallic Biomaterials Have Excellent Strength. Due To Rapid Inventions In Field Of New Materials In Medical Application Varieties Of Biomaterials Are Being Developed. Due To Challenges Imposed Strength Requirement And Life Of Bone Implants Still There Is A Lot Of Scope To Develop New Biomaterials To Replace Existing Ones. In This Investigation, Five Metallic Biomaterials Are Tested For Their Properties For Their Selection, Which Are Made Up Of Metal Matrix. For Selection Of Best Material Grey Relational Analysis (Gra) Is Used. Results Indicates That Gra Is Very Suitable Technique For Material Selection Problems Where One Have To Choose A Suitable Material From Many Options.*

***Keywords** - Biomaterial; Bone Implants; Compressive Strength; Grey Relational Analysis*

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I. Introduction :

Metallic Biomaterials Are Widely Used For The Fabrication Of Surgical Implants Because Of Their High Strength And Resistance To Fracture. Because Of These Properties They Can Provide Long-Term Implant Performance In Major Load-Bearing Situations. They Can Be Manufactured In Simple And Complex Shapes Using Commonly Used Manufacturing Processes Like Casting, Forging, Machining And Because Of This They Are Widely Used In Medical Application Particularly In Orthopaedics And Dentistry. Metallic Biomaterials Can Be Also Used For Artificial Heart Valves, Blood Conduits And Other Components Of Heart Assist Devices, Vascular Stents And Aneurysm Clips [1].

Over The Past Few Years The Demand For Implants Has Grown Radically. This Has Driven The Patient's Desire To Maintain Same Level Of Activity And Ageing Of Population [2]. Biomaterials Are Now Days Are Available In A Very Large Variety And Functional Possibilities. They Can Be Processed With Different Methods Of Processing And Assembly Into An Implantable Device. Wide Variety Of Synthetic, Natural And Hybrid Materials Currently In This Market [3].

This Paper Focuses On Selection Best Biomaterial Used For Orthopedic Implants. For Selection Of Best Option Grey Relational Analysis Is Used. Grey Relational Analysis (GRA) One Of The Useful Technique Which Is Normally Used For Optimization Problems Which Involve Multiple Responses. GRA Mainly Focuses On Deriving Grey Relational Grade (GRG). This GRG Provide Information On Factors Affecting Responses Used In The Investigation [4]. Selection Of Material For A Particular Application Is A Very Critical Task As Materials Now A Days Are Available Variety Of Properties. Therefore The Process Sometimes Is Very Confusing. Such Types Of Systems Are Frequently Called As Grey Which Gives Very Uncertain Information Of The Process. A Grey System Has A Level Of Information Between Black And White. Here Black Represents Things With No Information And White Represents Having All Information [5]. Through The Grey Relational Analysis, Optimization Of The Complicated Multiple Characteristics Is Transformed Into Optimization Of A Single Grey Relational Grade [6].

II. Development Of New Biomaterial

Development Of New Biomaterial To Replace Existing Metallic Biomaterial Having Better Properties As That Of Metals Is The Main Aim Of This Investigation. A New Bioceramic Composite Material Is Developed Containing HDPE, Alumina, Seashell And Eggshell. The Material Is Manufactured Using Extrusion And Moulding Processes [7]. The Five Samples Are Created By Varying The Amount Of HDPE And Reinforcement Contribution. The Description Of Samples Manufactured Is As Below. These Samples Are Tested To Determine Their Mechanical Properties.

Table 1 Material Composition Of Samples Of Newly Developed Biomaterial

Sr. No.	Specimen Designation	Polymer Matrix Composition HDPE (%)	Reinforced Particulates (%)		
			Particulate 1 Al2O3	Particulate 2 Seashell Powder	Particulate 3 Eggshell Powder
1	S1	60	10	15	15
2	S2	65	10	10	15
3	S3	70	10	10	10
4	S4	75	10	5	10
5	S5	80	5	5	10

III. Material Testing

The Developed Bioceramic Composite Material Is Tested For Three Major Mechanical Properties; Compressive Strength, Hardness And Wear. The Samples For Testing Are Prepared As Per ASTM Standards. The Measurement And Testing Is Done According To Standard Material Testing Procedure. The Results Obtained Are As Follows.

3.1 Compressive Testing

The Test Specimen Is Prepared As Per ASTM D695. The Testing Is Done Using UTM. The Results Generated For Compression Testing Are Given Below.

(A) (B)

Fig. 1 Sample S1 Before Compressive Testing (A) And After Compressive Testing (B)

Table 2 Summary Of Compression Test Results For Five Samples S1, S2, S3, S4, S5

Specimen No	Failure Peak Load (KN)	Deformation (Mm)	Compressive Strength (N/Mm^2)
S1	4.477	9.880	21.90
S2	5.000	9.520	22.707
S3	6.090	12.520	27.682
S4	6.280	14.800	28.545
S5	6.190	11.070	28.136

Samples S1, S2 Have Nearly Same Values Of Deformation And Compressive Strength Containing 60-65% HDPE And 35-40% Reinforcements. Samples S3, S4, S5 Have Approximately Equal Peak Load And Compressive Strength; But Have A Variable Deformation Value. In These Samples; Sample S4 Shows Maximum Deformation Of 14.80 Mm And Sample S5 Shows Minimum Deformation Of 11.07 Mm.

Sample S4 Is Having 75% HDPE Matrix And 25% Reinforcement And Sample S5 Having 80% HDPE And 20% Reinforcement. From Above Results, It Is Concluded That Sample S5, Containing 80% HDPE, 5% Alumina, 5% Seashell And 10% Eggshell Is Suitable For Applications Involving Compressive Forces Acting On Implant.

3.2 Hardness Testing

The Test Specimen Is Prepared As Per ASTM D2240. The Testing Is Done Using Vicker's Hardness Tester [8]. The Results Generated For Compression Testing Are Given Below.

(A) **(B)**

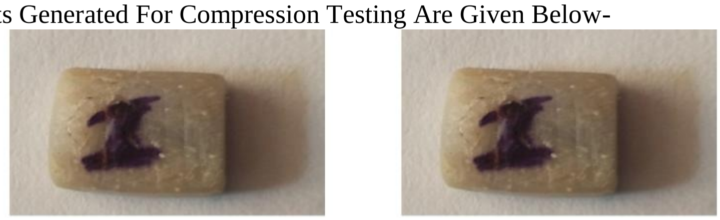
Figure 2 Sample S1 (A) Before Hardness Test And (B) After Hardness Test

Table 3 Summary Of Hardness Test Results

Sr. No.	Particulate Reinforcement	Sample No.				
		S1	**S2**	**S3**	**S4**	**S5**
1	Alumina (Al2O3)	152	134	112	87	116
2	Seashell	152	140	120	96	110
3	Eggshell	154	136	116	94	112
4	Average Hardness	152.7	136.7	116	93.2	112.7

3.3 Wear Testing

The Test Specimen Is Prepared As Per ASTM D-G99. The Testing Is Done Using Pin-On-Disk Wear Tester [9]. The Results Generated For Compression Testing Are Given Below-



(A) **(B)**

Figure 1 Sample S1 **(A)** Before Wear Test And **(B)** After Wear Test

Table 4 Summary Of Wear Testing Results

Type Of Reinforcement (µm)	HDPE Reinforced Composite Samples Wear (µm)				
	S1	S2	S3	S4	S5
Al2O3	30	36	44	50	58
Seashell	30	36	44	50	58
Eggshell	30	36	44	50	58
Average	30	36	44	50	58

IV. Decision Making Using Grey Relational Analysis

The Procedure Of Grey Relational Analysis Is As Follow [4-6]

Step 1: Normalization Of Raw Data

The First Step In Grey Relational Analysis Is Normalization Of Raw Data Obtained From Experimental Work. In This Investigation "Smaller-The-Better" Criterion Is Used For Normalization Of Deformation And "Larger Is Better" Is Used For Normalization Of Peak Load, Compressive Strength And Wear Resistance. These Can Be Calculated With Eq.1 And 2. Normalized Data Is Shown In Table 6.

$$x_i^*(k) = \frac{max\ x_i^{(o)}(k) - x_i^{(o)}(k)}{max\ x_i^{(o)}(k) - min\ x_i^{(o)}(k)} \qquad (1)$$

$$x_i^*(k) = \frac{x_i^*(k) - min\ x_i^0(k)}{max\ x_i^0(k) - min\ x_i^0(k)} \qquad (2)$$

Step 2: Determination Of Deviation Sequencethe Deviation Sequence $\Delta 0_i\ (k)$ Is The Difference Between The Reference Sequence $x_0{}^*(k)$ And The Comparability Sequence $x_i{}^*(k)$ After Normalization. It Is Determined Using Eq. 4 And Shown In Table 7.

$$\Delta 0_i\ (k) = |x_0{}^*(k) - \ x_i{}^*(k)| \qquad (4)$$

Step 3: Determination Of Grey Relational Coefficient
The Grey Relational Coefficient $\gamma(x_0(k), x_i(k))$ Can Be Expressed By Eq. 5.

$$\gamma(x_0(k), x_i(k)) = \frac{\Delta_{min}\ + \zeta\ \Delta_{max}}{\Delta_{0i}\ (k) + \zeta\ \Delta_{max}} \qquad (5)$$

Where, Δmin And Δmax Smallest And Largest Values Of Deviation Sequence.Z Is The Distinguishing Coefficient. The Value Of Z Can Be Defined In The Range Between 0 And 1; Here It Is Taken As 0.5.The Calculated Grey Relational Coefficients Are Shown In Table 8.

Step 4: Determination Of Grey Relational Grade
The Grey Relational Grade Is An Average Sum Of The Grey Relational Coefficients Which Is Estimated By Eq. 6.These Gardes Are Shown In Table 7.

$$\gamma\ (x_o, x_i) = \frac{1}{m} \sum_{\mathrm{I}=1}^{m} \gamma(x_0(k), x_i(k)) \qquad (6)$$

Step 5: Selection Of Best Option
This Is Done From Ranking The Options From Available Values Of Grey Relational Grade

V. Calculations Based On GRA

Table 5 Summary Of All Responses

Specimen No	Failure Peak Load (Kn)	Deformation (Mm)	Compressive Strength (N/Mm2)	Hardness(HV)	Wear Resitanance (µm)
S1	4.477	9.88	21.9	152.7	30
S2	5	9.52	22.707	136.7	36
S3	6.09	12.52	27.682	116	44
S4	6.28	14.8	28.545	93.2	50
S5	6.19	11.07	28.136	112.7	58

Table 6 Normalized Data

Normalization				
Failure Peak Load (Kn)	**Deformation (Mm)**	**Compressive Strength (N/Mm2)**	**Hardness(HV)**	**Wear Resitanance (µm)**
0.0000	0.9318	0.0000	1.0000	0.0000
0.2901	1.0000	0.1214	0.7311	0.2143
0.8946	0.4318	0.8701	0.3832	0.5000
1.0000	0.0000	1.0000	0.0000	0.7143
0.9501	0.7064	0.9384	0.3277	1.0000

Table 7 Deviation Sequences

Deviation Sequences				
Failure Peak Load (Kn)	**Deformation (Mm)**	**Compressive Strength (N/Mm2)**	**Hardness(HV)**	**Wear Resitanance (µm)**
1.0000	0.0682	1.0000	0.0000	1.0000
0.7099	0.0000	0.8786	0.2689	0.7857
0.1054	0.5682	0.1299	0.6168	0.5000
0.0000	1.0000	0.0000	1.0000	0.2857
0.0499	0.2936	0.0616	0.6723	0.0000

Table 8 Grey Relational Coefficients With Grades And Ranks

GRC					GRG	Ranks
0.3333	0.8800	0.3333	1.0000	0.3333	0.5760	4
0.4132	1.0000	0.3627	0.6503	0.3889	0.5630	5
0.8259	0.4681	0.7938	0.4477	0.5000	0.6071	3
1.0000	0.3333	1.0000	0.3333	0.6364	0.6606	2
0.9092	0.6301	0.8904	0.4265	1.0000	0.7712	1

VI. Conclusions

This Paper Presents A Very Interesting Paradigm Of Grey Relational Analysis For Selection Of Biomaterial For Othopedic Implants. Results From GRA Suggest That Sample 5 Is A Suitable Material For The Said Application. It Has A Very Good Combination Of Properties. Its Grey Relational Grade Is 0.7712 Which Is Very High As Compared To Rank 2 Material Which Is Sample 4. Sample 5 Has A Failure Peak Load Of 6.19 Kn, Deformation Of 11.07 Mm, Compressive Strength Of 28.136 N/Mm^2,Hardness Of 112.7 HV And Wear Resistance Of 58 µm.

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