Assessment of Suitability of Coating Systems for Subsea Systems

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Abstract: **A comprehension of the variables that assist with the actualization of good adhesion is of vast scientific and technological significance in order to gain control over the phenomenon of adhesion. To improve protection, operators should commence with the critical analysis of the materials to be deployed and their suitability for the site/field specific conditions. Till date, there are relatively few reported studies relating to coating functional chemistry, mechanical properties and performance. This paper thus evaluated in-depth, the different types of coating materials with respect to their suitability for subsea operations and identified the best practices to expand the life of coatings, and coated structures. The assessment of the economic and technical problems of coating materials, their application, and their service behavior for subsea/deepwater operations have been conducted using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). From the TOPSIS analysis, the best coating material considering the several criteria including: durability, resistance to stress, strength, adhesion, ductility, compatibility with cathodic protection and cost is Organic Coating which scored 0.653 followed by Nickel Alloy, with a value of 0.623 and the third best is Non-Ferrous Alloys.**

***Keywords*: Coating materials; Performance; Mechanical properties; Adhesion; Cathodic protection.**

I. INTRODUCTION

Aging or damaged offshore facilities pose significant difficulties to the offshore industry and operators globally. Currently, over 6,500 platforms and associated facilities, including pipelines are operating in about 50 countries. These facilities are of several sizes, shapes, and levels of robustness, some being installed in the 1950's and many operating well beyond their intended service life. Many of these existing facilities were designed in accordance with lower standards than are currently obtainable (Brasil *et al*., 2000). Others have experienced severe damage as a result of storms or accidents or, because of the lack of active maintenance programs have deteriorated to the extent that their future structural integrity is in question.

Addressing issues related to inspection, maintenance and the repair of platforms and pipelines is not new to the offshore industry. However, the increasing number of aging facilities, their share of the total production, their perceived susceptibility as well as the high cost of replacement have focused attention on their integrity and the need to establish acceptable guidelines including the thorough assessment of coating materials and systems prior to deployment. During economic downtime, and with the high cost of deepwater exploration and development, for some companies the maintenance of the existing older facilities is never a high priority, this calls for getting it right the first time with respect to the effectiveness of the material used for coating (Joanna, 2000).

Sixty percent of the global offshore fleet are beyond their design life of 20 years. With economic demands, the rigs are being deployed for an extended period of time well past their design life. Numerous other rigs are also getting to their 20-year design life. With aging of the rigs, there is a need to assess material strength and properties with respect to deterioration, that is, fatigue cracking and corrosion via proper and effective coating material selection (Mayer *et al*., 2000).

The deepwater environment is characterized with gale forces and aggressive weather conditions, and all subsea vessels and other deepwater structures require protection from corrosion (Elijah, and Obaseki, 2021). Surface treatment technologies have been attracting a great deal of attention because they provide cost-effective strategies to inhibit the degradation resulting from mechanisms such as wear, oxidation, corrosion, or failure under an excessive heat load without sacrificing the bulk properties of the component material.

Several surface modification technologies are available (Sundararajan *et al*., 1997) providing a wide range of quality and cost. Since a vast majority of industrial components deteriorate and eventually fail due to one of several wear modes that may be encountered during normal operation (Sundararajan, 1994), significant attention has been given to the development of coating materials and processes specifically to inhibit the routine wear modes, including erosion, abrasion, and sliding wear. The choice of the coating system is a function of the location of its application, such as the hull, waterline area, topsides, decks, interior, and tanks, etc. Owing to their low cost, availability, and ease of application, paints and other coating materials have been the preferred method of topside protection. Advances in zinc, polyurethane and powder coating technologies make them a superior alternative to epoxy resin technology for longer-term service life. Zinc provides corrosion protection as thin coatings, polyurethane is effective and aesthetically appealing, while powder coatings can meet the environmental and regulatory challenges. The present need for subsea coatings go beyond performance, as they are also required to comply with various environmental regulations (Bennett, 2001).

Much progress has been made in the practice of using coating technology to offer corrosion protection to offshore structures, inner-hull tanks in fuel tankers, ship hulls, underwater pipes, etc. New methods have been developed to repair and protect concrete and steel structures in coastal and offshore waters, such as the all-polymer encapsulation technique to repair and protect structures in the splash zone (Knight, 2001). When designing any structure for service in an aggressive offshore environment, undesirable outcomes (such as overdesign, structural failure, costly and inadequate maintenance, product loss, production downtime and inefficiency) will likely occur, unless they are considered during the design process (Power, 2001). Long-term structural or mechanical requirements for a particular application can be assured through corrosion protection, through either coatings or a combination of cathodic protection and coatings.

Advances in coating technology can offer tremendous cost saving if developed and successfully implemented. Metallic coatings are required to improve the surface properties such as mechanical and chemical resistance, and it is also recommended that the technology to produce the coating should be environmentally friendly. In order to serve as an effective protection system, the coating should exhibit certain characteristics with respect to corrosion protection, such as limited water permeability, ionic resistance, good adhesion, and certain mechanical properties. Also, the coating needs to withstand severe weather including extreme temperatures (Ruschau and Beavers, 2000). The choice of coating material goes a long way to determine how well or not the coating system serves as an effective protection system.

There are relatively few reported studies relating to coating functional chemistry, mechanical properties and performance (Kojio *et al*., 2012). However, an understanding of the factors which help to achieve good adhesion is clearly essential in understanding the phenomenon of adhesion, and increasing the efficacy of the coating system Thus, this paper assessed the different types of coating materials per their suitability for subsea operations and identified the best practices to extend the life of coatings using The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). In the paper, the existing coating materials were evaluated and compared under some critical factors and also based on economics.

II. METHODOLOGY

Technique of Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is one of the most useful Multi Attribute Decision Making (MADM) techniques that are very simple and easy to implement, such that it is used when the user prefers a simpler weighting approach. TOPSIS method was firstly proposed by Hwang & Yoon (1981). According to this technique, the best alternative would be the one that is nearest to the positive ideal solution and farthest from the negative ideal solution (Benitez *et al*., 2007). The positive ideal solution is a solution that maximizes the benefit criteria and minimizes the cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria (Wang & Chang, 2007; Wang & Elhag, 2006; Wang & Lee, 2007; Lin *et al*., 2008). In other words, the positive ideal solution is composed of all best values attainable of criteria, whereas the negative ideal solution consists of all worst values attainable of criteria (Ertuğrul & Karakasoğlu, 2009).

A MADM problem with *m* alternatives (*A1*, *A2*,….,*Am*) that are evaluated by *n* attributes (*C1*, *C2*,…., *Cn*) can be viewed as a geometric system with *m* points in *n*-dimensional space. An element xij of the matrix indicates the performance rating of the *i*th alternative, *Ai*, with respect to the *j*th attribute, *Cj*, as shown below:

	A1	C1 x11 . . . . . Cn x1n x11	C2 x12	C3 x13	. .	. .	. .	Cn x1 n
	A2	x21	x22	x23	.	.	.	x2 n
	A3	x31	x32	x33	.	.	.	x3 n . .
D =	.	.	.	.	.	.	.	
	.	.	.	.	.	.	.	
	.	.	.	.	.	.	.	.
	Am	xm1	xm2	xm3	.	.	.	xm n

The terms used in the study are briefly defined as follows:

Attributes: Attributes (*Cj*, *j* = 1, 2,….,*n*) should provide a means of evaluating the levels of an objective. Each alternative can be characterized by a number of attributes.

Alternatives: These are synonymous with 'options'. Alternatives (*Ai*, *i* = 1,2, …., *m*) are mutually exclusive of each other.

Attribute weights: Weight values (*wj*) represent the relative importance of each attribute to the others. *W* = {*wj*|*j* = 1, 2, .,*n*}.

Normalization: Normalization seeks to obtain comparable scales, which allows attribute comparison. The vector normalization approach divides the rating of each attribute by its norm to calculate the normalized value of *xij* as defined below:

$$rij \; = x_{ij} / \left(\Sigma x_{ij}^{2}\right)^{\frac{1}{2}} \text{for i} = 1\ldots \text{ m; j} = 1, \ldots, \text{n} \quad (1)$$

Given the above terms, the formal TOPSIS procedure is defined as follows:

Step 1: Construct normalized decision matrix. This step transforms various attribute dimensions into non-dimensional attributes, which allows comparisons across criteria.

Step 2: Construct the weighted normalized decision matrix. Assume a set of weights for each criteria *wj* for *j = 1,…,n*. Multiply each column of the normalized decision matrix by its associated weight. An element of the new matrix is:

vij = wjrij, for *i* = 1, 2,…, *m; j* = 1, 2,…, *n* (2)

Step 3*:* Determine the positive ideal (*A**) and negative ideal (*A–*) solutions. The *A** and *A–* are defined in terms of the weighted normalized values, as shown in the equations below:

Positive Ideal solution

$A^{*} = \{v_1^{*} \ldots v_n^{*}\}$, where

$$v_j^{*} = \{ max\,(v_{ij})\; if\; j \in J\,;\;\; min\,(v_{ij})\; if\;\; j \in J\} \qquad (3)$$

where *J* is a set of benefit attributes (larger-the- better type) and *J'* is a set of cost attributes (smaller-the-better type).

Negative ideal solution.

$A^{'} = \{v_1^{'} \ldots v_n^{'}\}$, where

$$v^{'} \; = \{ max\,(v_{ij})\; if\; j \in J\,;\;\; min\,(v_{ij})\; if\;\; j \in J'\} \qquad (4)$$

Step 4*:* Calculate the separation measures for each alternative. The separation of each alternative from the positive ideal alternative is:

$$S_i^{*} = \left[\Sigma\left(v_j^{*} - v_{ij}\right)^{2}\right]^{\frac{1}{2}} \quad \text{i} = 1, \ldots, \text{m} \qquad (5)$$

Similarly, the separation of each alternative from the negative ideal alternative is:

$$S_i^{'} = \left[\Sigma\left(v_j^{'} - v_{ij}\right)^{2}\right]^{\frac{1}{2}} \qquad \text{i} = 1, \ldots, \text{m} \qquad (6)$$

Step 5*:* Calculate the relative closeness to the ideal solution or similarities to ideal solution Ci*

$$C_i^{*} = S_i^{'} / (S_i^{*} + S_i^{'}),\, 0 < C_i^{*} < 1 \qquad (7)$$

Step 6: By comparing *Ci* values, the ranking of alternatives is determined. Choose an alternative with maximum *Ci** or rank alternatives according to *Ci ** in descending order.

Topsis Algorithim

The TOPSIS algorithm starting from the decision matrix construction to the ranking of the alternatives according to their relative proximity is shown in Figure 1.

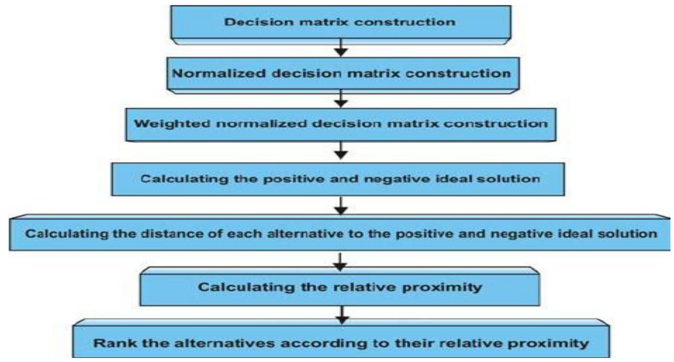

Figure 1: TOPSIS Algorithm

Input to TOPSIS

TOPSIS considers m number of options to select from and n factors to base the selection on and one must score each option against the corresponding factors.

Assume x_{ij} score of option i with respect to factor j, a matrix X = (x_{ij}) m×n matrix is formed. J is the set of positive attributes (the more, the better) and J' is the set of negative attributes (the less, the better). Each factor can be scored certain points on a scale of 0-10 0r 0-100 by the experts (Assari *et al*., 2012).

Alternatives

Applying TOPSIS to this study; m = 10 alternatives/options (Carbon Manganese Steel (CMS), Cast Iron (CI), Stainless Steel (S.S), Non-Ferrous Alloys (NFA), Nickel Alloys (NA), Titanium Alloys (TA), Organic Coating (OC), Polyurea Coating (PUC), Powder Coating (PC), and Rubber Linings (RL)).

Carbon manganese steel is not an efficient corrosion resistant material and must be protected by means of cathodic protection other systems. This type of steel is still considered, because it is the most commonly utilized material for pipelines in offshore. When deployed for coatings, the corrosion is also controlled by cathodic protection in case of coating damages, thereby incurring added cost. High grade steel, stainless steel and cast iron. With respect to the utilization of high strength steel (yield strength > 450MPa) in offshore and marine environments, hydrogen embrittlement (HE) and corrosion fatigue are associated problems (Morada, 2015).

Cast iron: Though most cast iron grades have a good corrosion resistance to water and atmospheric conditions, they are not resistant to chlorine containing environments.

Stainless steel can be utilized in offshore components although the material cost is much higher than the unalloyed and alloyed steels that are commonly used for structural and piping solutions. The stainless steels are corrosion resistant because of the high chromium content (> 12% Cr) besides other elements like nickel and molybdenum etc. The chromium is especially responsible for the corrosion resistance of steel because of the formation of a thin but adhering chromium oxide layer at its surface that reduces corrosion. However most austenitic stainless steels like EN 1.4301 (AISI 304) have a moderate corrosion resistance, depending on the environment. Two issues can result: sensitization after welding and local corrosion (pitting) due to free chlorine and sulfate ions (Cunat, 2002).

Non-ferrous alloys like aluminium, copper-nickel, nickel and titanium can be utilized in offshore construction in spite of their lower mechanical properties and higher cost compared to steel.

Nickel and nickel-based alloys have the best corrosion resistance for almost every chemical product, especially for sulfate and chloride containing environments. There exist a number of commercial nickel alloys. These alloys are not subject to chloride stress corrosion cracking as compared to other stainless steels and their pitting resistance is extremely high making these alloys suitable for fasteners and other fixing equipment in extreme harsh conditions. The high price of these alloys however makes them rather unsuitable as a substrate for constructive elements like pillars and girders (Banker, 1996).

Titanium has increasing applications in marine structures over the last years despite its higher cost compared to steel and stainless steel (Banker, 1996). The four principal areas of application have been its strength per weight advantage (highest of all metals), its complete immunity to corrosion by seawater (0.01 mm/year), its heat transfer capability, and its high corrosion fatigue limits in both low and high cycle fatigue. Titanium alloys are lighter than steel and have excellent mechanical properties making them useful for constructive parts with high corrosive demands. The applications in offshore are stress joints, pipes, water tanks, sleeves, manholes etc. (Banker, 1996).

Organic coatings are the most frequently used anti-corrosion solution in many industries, including the offshore sector. Typically, a multilayer system consisting of a primer, 2-3 intermediate coats and a topcoat is applied. The primer can be paint based, but often metallization is also used as a ‘primer’ layer.

Polyurea coatings combine exceptional physical properties such as high hardness, very good flexibility, good tear strength, tensile strength, chemical and water resistance. Polyurea systems are very tough, combining high elasticity with high surface hardness, resulting in very good abrasion resistance. They also have very good barrier properties due to the high density of polyurea coatings. This makes that polyurea coatings combine a very good corrosion protection with excellent weathering and abrasion resistance.

Powder coating is an organic coating that is applied as a free-flowing, dry powder. The main difference between a conventional liquid paint and a powder coating is that the powder coating does not require a solvent to keep the binder and filler parts in a liquid suspension form. This has several environmental benefits, as no VOC’s are required. The powder is typically deposited electrostatically and then cured under heat (150-200 °C).

Powder coatings offer a number of benefits compared to liquid coatings. In many cases, they perform better and last longer than traditional wet paints. Powder coatings are very durable and corrosion resistant. Powder coatings provide corrosion protection by being very good barrier layers. Compared to liquid coatings, most powder coatings are also more resistant to chips, scratches, wear and fading, and they retain their brightness and vibrancy longer (Hoover *et al*., 1937).

Rubber linings have been extensively used for protecting carbon steel equipment against corrosion and abrasion (Detty *et al*., 2015) and they are still used in the most aggressive processes of chemical industry. Rubber compounds show strong adhesion to carbon steel, which makes them suited for being used as coatings and linings. There are many different types of rubbers depending on its chemical structure and properties. One of the most prominent is chloroprene rubber (most known by its commercial name neoprene) due to its flexibility and outstanding resistance against ozone, sea water and weathering. Due to its remarkable mechanical properties and outstanding resistance to weathering, chloroprene rubber is nowadays one of the most adapted materials for mechanical and anticorrosion protection of clamps and supports of offshore secondary steel (J-tubes, grouting, Boat-landing stairs and other)

Criteria

The broad criteria for the comparison and analysis will include: Adhesion, Ductility, Strength, Compatibility with Cathodic Protection, Durability, Cost and Resistance to Corrosive Stresses due to increased salt levels in water, impact loading and biological stress. Under the cost criterion, sub-criteria will include: application and surface preparation costs. The flow algorithm for the decision criteria is shown in Figure 2.

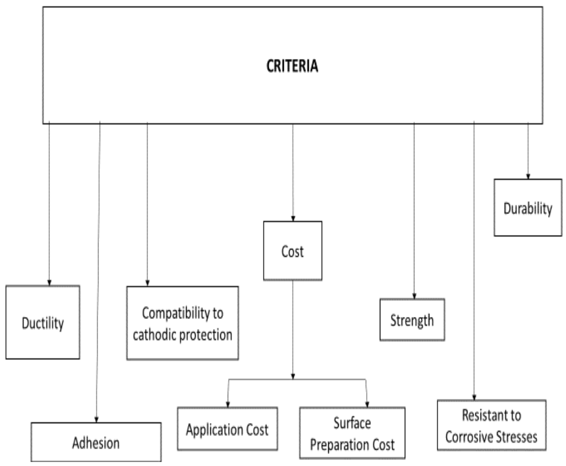

Figure 2: TOPSIS Criteria Algorithm

Input Data

Base on the data obtained from experts' survey in corrosion, the following rating were obtained for criteria per weight

Table 1: Assigned weights to the criteria

CRITERIA	WEIGHT	RATING SCALE
Durability	0.9	Scale of 1 (1 means very important, 0 means not important)
Resistance to stresses	0.9	
Strength	0.9	
Adhesion	0.9	
Ductility	0.9	
Compatibility to Cathodic Protection	0.6	
Cost (Surface Preparation & Application)	0.7	

From the responses obtained, the highest number of responses per percentage is chosen as a rating for that particular option.

Table 2: xij = score of option i with respect to criterion j

Criteria	CMS	CI	SS	NFA	NA	TA	OC	PUC	PC	RL	Rating Scale
Durability	3	7	7	6	9	10	8	8	8	8	(1-10) 1 means very poor, 10 means very excellent
Resistance to stress	4	8	9	6	10	9	7	9	8	9	
Strength	4	7	8	6	9	9	7	8	8	8	
Adhesion	3	7	8	7	9	9	8	8	8	8	
Ductility	4	7	7	6	9	10	7	8	8	9	
Compatibility with CP	8	6	6	6	6	5	7	8	6	6	
Cost	3	6	5	4	4	4	4	7	7	6	

III. RESULTS AND DISCUSSIONS

TOPSIS Comparative Analysis

Applying TOPSIS to the study; m = 10 alternatives and n = 7 broad attributes/criteria, which are all presented in Table 3. These weighting has been done by a team of experts based on how important they thought each criterion was with respect to the theme of the study. The average of the weighting for each criterion is provided as shown in Table 3. xij = score of alternative i with respect to attribute j as shown in Table 4. J = set of benefit attributes: high durability, high resistance to stresses, excellent adhesion, excellent ductility, high compatibility with cathodic protection and low cost. Also, experts assigned scores to each of the options with respect to the criteria under consideration. Their average scores for each of the options is provided as shown in Table 4.

Prior research works were used to ascertain the strengths, the limitations and drawbacks of each of the option considered in this analysis. These strengths and drawbacks also guided the experts in assigning weights to the alternatives against specific criteria.

With Tables 3 and 4 in place, the TOPSIS analysis steps were then applied as shown below:

The normalized decision matrix $rij = x_{ij} / \left(\Sigma x_{ij}^2\right)^{\frac{1}{2}}$ as shown in Table 5. The weighted normalized decision matrix $v_{ij} = w_j r_{ij}$ was developed by multiplying each column of the normalized decision matrix by its associated weight.

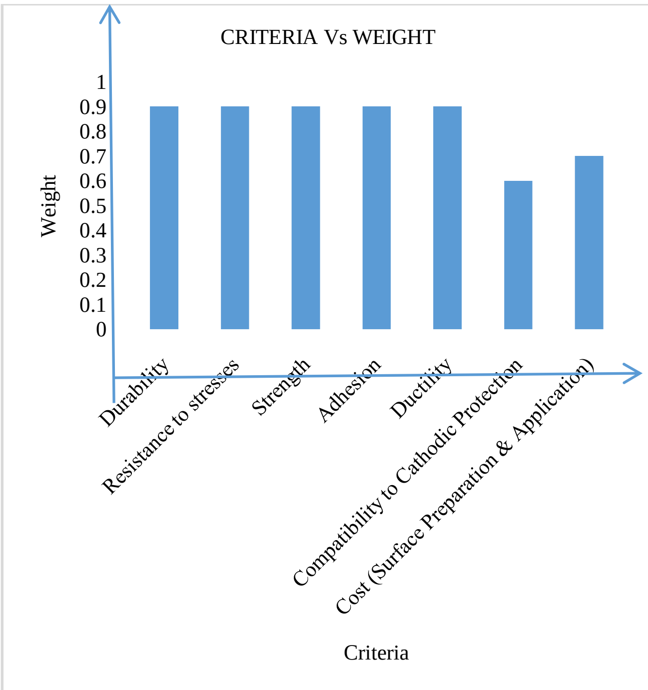

Figure 3: The assigned weights to the criteria

Figure 3 shows importance of each of the criteria i.e., Durability, Resistant to stresses, strength, Adhesion, Ductility, Compatibility to cathodic protection and cost (Surface preparation and Application) per weight. This result obtained the variation of the criteria with respect to their importance (weight) of coating systems on subsea structures on a scale of zero to one (0-1), zero is very poor and one is very good or excellent. All the criteria are very good per weight except compatibility to cathodic protection and cost giving a relatively lower scores to other criteria.

A set of maximum values for each criterion also known as the ideal solution $A^* = \{v_1^* \dots v_n^*\}$was developed as shown under step 3 below. Similarly, a set of minimum values for each criterion also known as the Negative ideal solution $A' = \{v_1' \dots v_n'\}$ was developed as shown in step 3.

The separation from the ideal alternative $S_i^* = \left[\Sigma\left(v_j^* - v_{ij}\right)^2\right]^{\frac{1}{2}}$ was computed. Similarly, the separation from the negative ideal solution, $S_i' = \left[\Sigma\left(v_j' - v_{ij}\right)^2\right]^{\frac{1}{2}}$ was also computed. Finally, the relative closeness to the ideal solution $C_i^* = S_i'/(S_i^* + S_i')$ was computed and the results are as shown in Table 8.

The decision matrix for the options rating is shown in table 4.

Table 3xij = score of option i with respect to criterion j

Criteria	CMS	CI	SS	NFA	NA	TA	OC	PUC	PC	RL	Rating Scale
Durability	3	7	7	6	9	10	8	8	8	8	(1-10) 1 means very poor, 10 means very excellent
Resistance to stress	4	8	9	6	10	9	7	9	8	9	
Strength	4	7	8	6	9	9	7	8	8	8	
Adhesion	3	7	8	7	9	9	8	8	8	8	
Ductility	4	7	7	6	9	10	7	8	8	9	
Compatibility with CP	8	6	6	6	6	5	7	8	6	6	
Cost	3	6	5	4	4	4	4	7	7	6	

Applying TOPSIS in the analysis resulted to:

Step 1(a): Standardizing the decision matrix

This step makes the ratings dimensionless by dividing each column of the decision matrix by root of sum of square of respective rows. The result of this is shown in table 6.

Step 1 (b): divide each column by $\left(\Sigma x_{ij}^2\right)^{\frac{1}{2}}$ to get r_{ij} which is the standardized decision matrix as shown in table 6.

Step 2: Develop weighted standardized decision matrix by multiplying the criteria weight (see Table 4) with each rating in Table 6.

Step 3: Determine ideal alternative and negative ideal alternative

A set of maximum values for each criterion is the ideal alternative while a set of minimum values for each criterion is the negative ideal alternative.

Ideal alternative A*: {0.374, 0.352, 0.340, 0.334, 0.371, 0.235, 0.299}

Negative ideal alternative A': {0.224, 0.211, 0.227, 0.260, 0.222, 0.147, 0.171}

Step 4 (a): Determine separation S_i^* from ideal solution (A*).

$S_i^* = \left[\Sigma\left(v_j^* - v_{ij}\right)^2\right]^{\frac{1}{2}}$ for each column.

$\boldsymbol{S_i^* = \left[\Sigma\left(v_j^* - v_{ij}\right)^2\right]^{\frac{1}{2}}}$ **= {0.216, 0.200, 0.320, 0.151, 0.159, 0.231, 0.123, 0.150, 0.128, 0.215}**

Step 4 (b): find separation from negative ideal solution (A') and $S_i^{'} = \left[\Sigma\left(v_j^{'} - v_{ij}\right)^2\right]^{\frac{1}{2}}$ for each column as shown below.

$\boldsymbol{S_i^{'} = \left[\Sigma\left(v_j^{'} - v_{ij}\right)^2\right]^{\frac{1}{2}}}$ **= {0.312, 0.154, 0.029, 0.253, 0.272, 0.120, 0.232, 0.201, 0.211, 0.132}**

Table 4 Computation of $\left(\Sigma x_{ij}^2\right)^{\frac{1}{2}}$

CRITERIA	CMS	CI	SS	NFA	NA	TA	OC	PUC	PC	RL	$\left(\Sigma x_{ij}^2\right)^{\frac{1}{2}}$
Durability	3	7	7	6	9	10	8	8	8	8	24.08
Resistance to stress	4	8	9	6	10	9	7	9	8	9	25.55
Strength	4	7	8	6	9	9	7	8	8	8	23.83
Adhesion	3	7	8	7	9	9	8	8	8	8	24.27
Ductility	4	7	7	6	9	10	7	8	8	9	24.27
Compatibility with CP	8	6	6	6	6	5	7	8	6	6	20.45
Cost	3	6	5	4	4	4	4	7	7	6	16.37

Table 4 show a normalized computation, this step transforms the various attribute into non-dimensional.

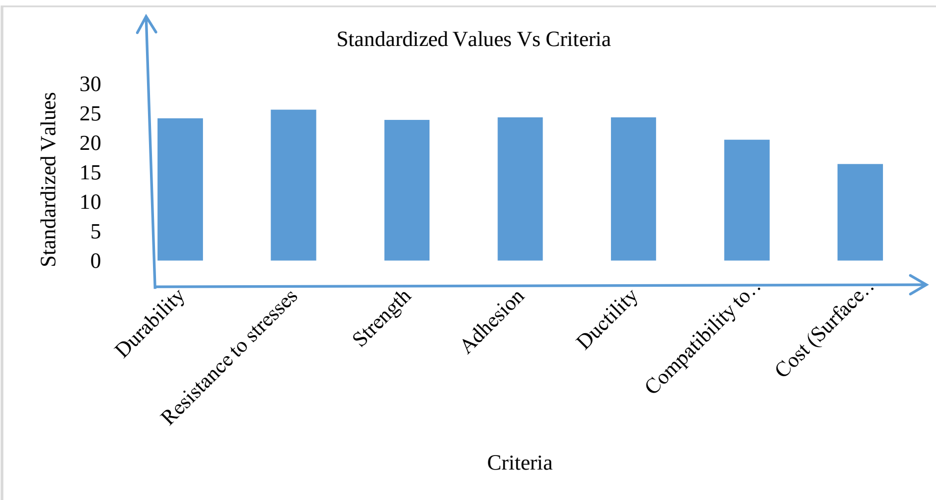

Figure 4: Standardized Criteria Values

Figure 4 shows a standard criteria value on graph.

Table 5: The normalized decision matrix $rij = x_{ij} / \left(\Sigma x_{ij}^2\right)^{\frac{1}{2}}$

CRITERIA	CMS	CI	SS	NFA	NA	TA	OC	PUC	PC	RL
Durability	0.291	0.291	0.249	0.374	0.415	0.332	0.332	0.332	0.332	0.291
Resistance to stress	0.313	0.352	0.235	0.391	0.352	0.274	0.352	0.313	0.352	0.313
Strength	0.294	0.336	0.252	0.378	0.378	0.294	0.336	0.336	0.336	0.294
Adhesion	0.288	0.330	0.288	0.371	0.371	0.330	0.330	0.330	0.330	0.288
Ductility	0.288	0.288	0.247	0.371	0.412	0.288	0.330	0.330	0.371	0.288
Compatibility with CP	0.293	0.293	0.293	0.293	0.244	0.342	0.391	0.293	0.293	0.293
Cost	0.367	0.305	0.244	0.244	0.244	0.244	0.428	0.428	0.367	0.367

Table 6: The weighted normalized decision matrix $v_{ij} = w_j r_{ij}$

CRITERIA	CMS	CI	SS	NFA	NA	TA	OC	PUC	PC	RL
Durability	0.262	0.262	0.224	0.336	0.374	0.299	0.299	0.299	0.299	0.262
Resistance to stress	0.282	0.317	0.211	0.352	0.317	0.247	0.317	0.282	0.317	0.282
Strength	0.264	0.302	0.227	0.340	0.340	0.264	0.302	0.302	0.302	0.264
Adhesion	0.260	0.297	0.260	0.334	0.334	0.297	0.297	0.297	0.297	0.260
Ductility	0.260	0.260	0.222	0.334	0.371	0.260	0.297	0.297	0.334	0.260
Compatibility with CP	0.176	0.176	0.176	0.176	0.147	0.205	0.235	0.176	0.176	0.176
Cost	0.257	0.214	0.171	0.171	0.171	0.171	0.299	0.299	0.257	0.257

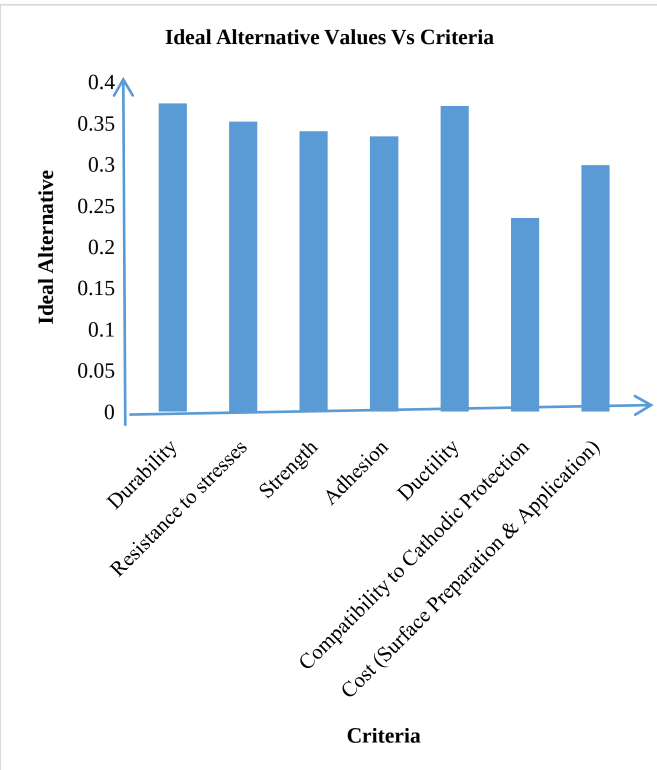

Figure 5: Criteria Vs Ideal Alternative Values

From the results obtained in Table 5, Table 6 and Figure 5 and ideal alternative and negative ideal alternative were obtained. The ideal alternative has 0.374,0.352,0.340,0.334,0.0371,0.235, and 0.299 (the maximum value from each row), for each of the ten (10) coating systems respectively. The implication is that NA, NFA, NA, NFA, NA, OC, and OC have the maximum durability, resistant stresses, strength, Adhesion, Ductility, Compatibility to Cathodic Protection and Cost respectively.

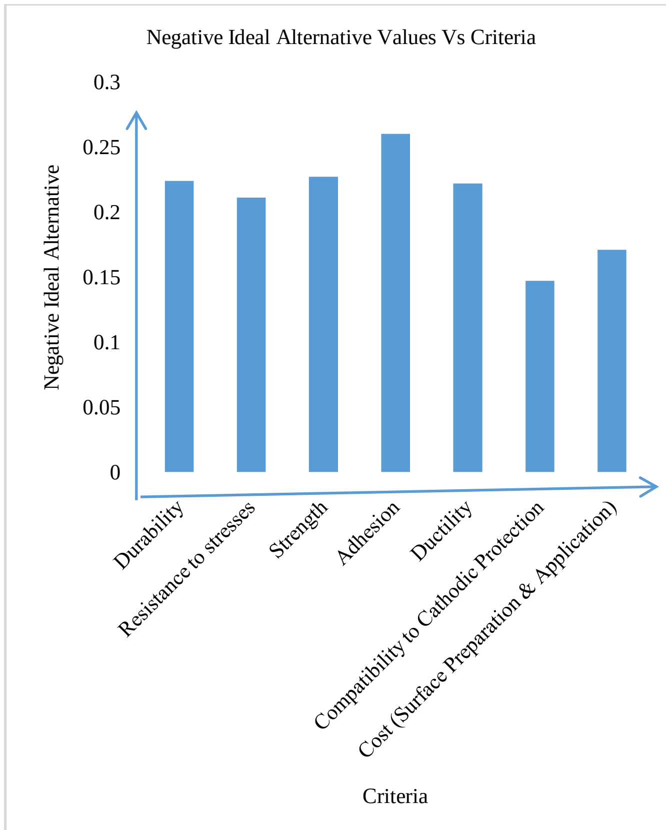

Figure 6: Criteria Vs Negative Ideal Alternative Values

Figure 6 shows ideal negative alternative are 0.224,0.211,0.227,0.260,0.222,0.147 for and 0.171 for SS, NFA, NA and CMD, SS,NA and SS,NFA,NA have least Durability, Resistant to Stresses, Strength, Adhesion, Ductility, Compatibility to Cathodic Protection and Cost respectively on subsea structures.

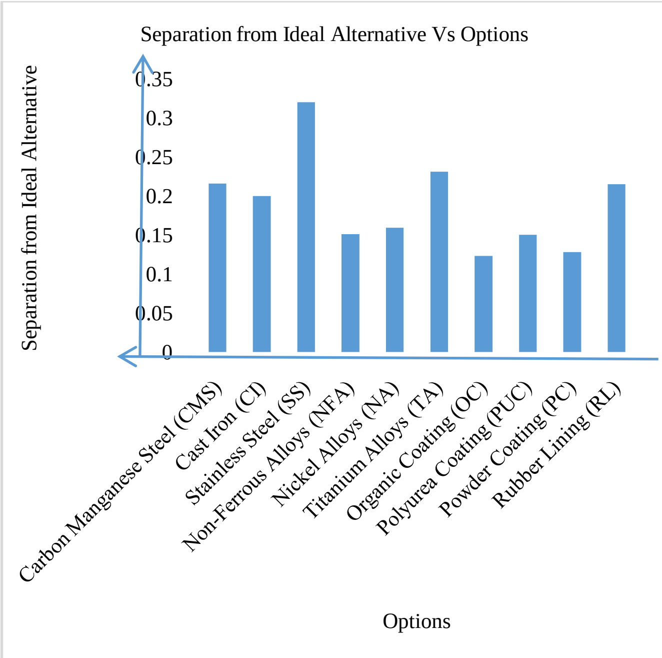

Figure 7: Alternatives Vs Values for Separation from ideal alternative

Figure 7 shows separation of all the coating option to an ideal system that will suit subsea structures, higher values are eliminated as least coating options.

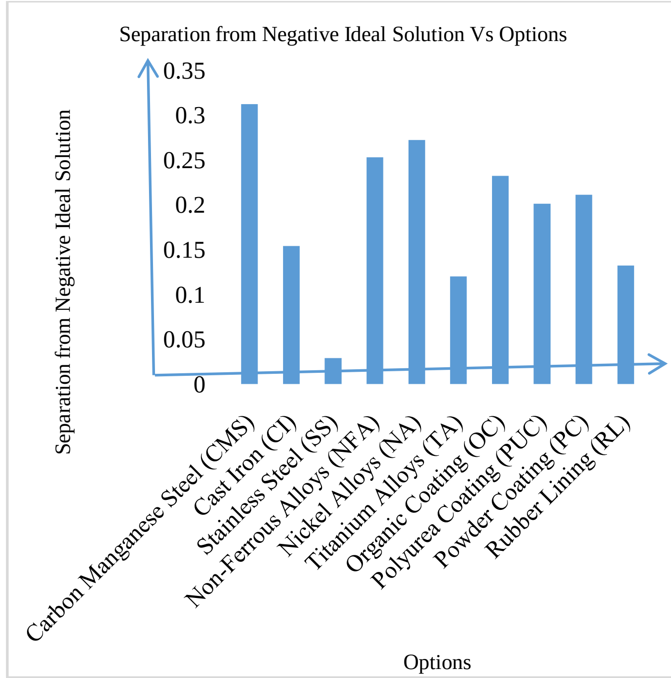

Figure 8: Options Vs Values from Separation from Negative Ideal Solution

Step 5: Calculate the relative closeness to the ideal solution $C_i^* = S_i^{'}/(S_i^* + S_i^{'})$ The matrix of the closeness to the ideal solution is provided in Table 8

Table 8: Computation and results of the relative closeness to the ideal solution $C_i^* = S_i^{'}/(S_i^* + S_i^{'})$

	CMS	CI	SS	NFA	NA	TA	OC	PUC	PC	RL
Si*	0.216	0.200	0.320	0.151	0.159	0.231	0.123	0.150	0.128	0.215
Si'	0.132	0.154	0.029	0.253	0.272	0.120	0.232	0.201	0.211	0.132
Si*+Si'	0.348	0.354	0.349	0.404	0.431	0.351	0.355	0.351	0.339	0.347
Si'/(Si*+Si')	**0.380**	**0.436**	**0.083**	**0.627**	**0.631**	**0.342**	**0.653**	**0.573**	**0.623**	**0.380**

Table 8 shows a computation of various options and a relative closeness to the ideal solution of the various coating system was obtained.

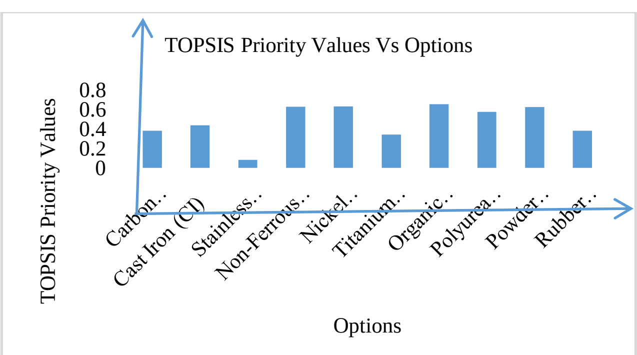

Figure 9: The Options' TOPSIS Scores

Figure 9 shows where a ranking alternative was determined and a maximum value was equally obtained. This also shows that OC, NA, NFA and PC scored 0.653,0.631,0.627 and 0.623 respectively. The maximum value (most ideal solution) is Organic Coating having a score of 0.653.

Therefore, having gone through all the steps in TOPSIS analysis, the best coating material considering the several criteria including: durability, resistance to stress, strength, adhesion, ductility, compatibility with cathodic protection and cost is **Organic Coating** which scored 0.653, which is the perfect value of relative closeness to the ideal solution of 1 in this study.

From the TOPSIS analysis, the second-best coating material is the Nickel Alloy, with a value of 0.631, followed by Non-Ferrous Alloys. Hence, the implication of this finding is that the Organic Coating is the most suitable (technically and economically) for subsea deployment.

IV. CONCLUSIONS

The selection of coating systems for offshore structures is not straightforward. If the protective coatings around the structure is lost, the structure will be exposed to the environment. This environment (mostly seawater) will contain water and oxygen, which will cause corrosion if there is no coating protection.

Therefore, to enhance protection, operators should begin with the critical evaluation of the materials to be deployed and their suitability for the site/field specific conditions. In this study:

i. TOPSIS analysis was applied over ten alternatives/options and seven attributes/criteria.
ii. From the TOPSIS analysis, the best coating material considering the several criteria including: durability, resistance to stress, strength, adhesion, ductility, compatibility with cathodic protection and cost is **Organic Coating** which scored 0.653 followed by Nickel Alloy, with a value of 0.6231 and the third best is Non-Ferrous Alloys.
iii. Hence, the implication of this finding with respect to the subject matter is that the Organic Coating is the most suitable coating material (technically and economically) for subsea deployment.

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