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CHOOSING A PROPER METHOD FOR STRENGTHENING WPC BEAMS WITH GROOVING METHOD USING SWARA-EDAS

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Abstract: Wood plastic composite (WPC) is a lightweight material, resistant against corrosion and damage, with recyclability of consuming materials. These materials usually used in marine structures frequently due to their unique features. In order to strengthen beams made by this material, usually Fibre-reinforced plastic (FRP) sheets are used, and one of the fracture modes in these beams is debonding of FRP sheet from the surface of the beams. To deal with this problem some grooves are used in the surface of the beam to improve the contact surface. The grooves include longitudinal, transverse and diagonal grooves. The main goal of this study is to assess different grooving methods in WPC-FRP beams. In this regard, primarily criteria (improving resistance, performance speed, performance complexity, performance costs, displacement and absorbing energy) were determined through interviews with experts in this field in order to assess the beams. Then, SWARA method employed to evaluate criteria with a policy based perspective and finally EDAS method applied for evaluating related alternatives. Based

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on obtained results, the longitudinal groove method is the best way of strengthening WPC beams to prevent debonding.

Keywords: Wood Plastic Composite (WPC); Debonding; Grooving; Fibre-reinforced plastic (FRP); Step-wise Weight Assessment Ratio Analysis (SWARA); Evaluation Based on Distance from Average Solution (EDAS)

1. INTRODUCTION AND LITERATURE REVIEW

Wood Plastic Composite (WPC) is a lightweight material, resistant against corrosion and damage, with recyclability of consuming materials that obtained from combination of wood and plastic scum. Typically, some materials such as steel, concrete and wood are used to build these structures and because they are always exposed to damages such as corrosion and erosion, retrofitting and replacement of some parts is done in order to insure their health and durability.

As a new brand material, WPC has been positively applying in so many construction uses and is created by mixture of wood (shape of sawdust) and polymeric resources [1-6].

Wangaard [7] as one of pioneers did a study on fiber-reinforced polymer used in wooden structures with both experimental and theoretical measures to investigate and compare the elastic deflection values of wood–fibreglass composite beams.

Haiar [8] has focused on characterizing Poly-Vinyl Chloride (PVC) and High Density Polyethylene (HDPE) WPC blends to use in structural applications. Nowadays, it can be seen in the literature that wooden structures reinforced with FRP composites have been applying in the different sub-fields of Civil Engineering such as bridges, railroad ties etc. [9-12].

In spite of the effective role of the FRP sheets that can be play in the flexural strengthening of the WPC elements, they have an important deficiency in the beam bonding. Consequently, early failure due to the de-bonding of beams, result in wastage of the beam designed capacity. In this regards, one of the previous researches by using some laboratory studies is carried out in order to present the main weakness of the FRP sheets in the surface un-bounding and the applicability and productivity of the FRP sheets with WPC materials [13]. Hence, combination of the FRP and WPC would enhance the performance and decrease the deficiencies simultaneously.

Many researches in regarding of grooving method have done. Mostofinejad and Kashani [14] presented this method for the first time by concrete structure and also the research focused on postpone debonding of FRP Laminates in concrete beams and the results showed that by using grooving method debonding from the plate surface is delayed or completely prevented in most cases. Naghipour *et al.* [15] used longitudinal groove for attaching GFRP sheet to WPC surface. Finally, the result showed that the use of longitudinal grooves resulted in resistance improvement. Lale Arefi *et al.* [16] have evaluated the grooving method including various shapes such as diagonal grooves, transverse grooves and longitudinal grooves, in the debonding control of beams reinforced by FRP sheets; compare their treatment such as Force-displacement diagram; determine the failure mode and the ultimate failure load by changing the width, depth, and shapes of grooves; and determine the number of reinforcement layers.

When FRP sheets are used to strengthen the reinforced concrete beams, efficiency of different confinement methods such as Externally Bounded Reinforcement (EBR) and Externally Bounded Reinforcement On Grooves (EBROG), in different flexural failure mechanisms are investigated in the previous studies [17; 18]. This research examined many samples in laboratory and finally showed that using the grooving method leads to increased ultimate load carrying capacity in the beams, also. Mostofinejad *et al.* [19] investigated on EBROG and EBRIG methods in reinforcement concrete beams that involved FRP sheets. The considerated specimens were subjected under flexural loading. Finally result showed the capacity load in EBROG and EBRIG method compared to EBR method was increased.

Moshiri *et al.* [20] have done researches on strengthening of reinforcement concrete columns by using of grooving method. They showed that using grooving method postponed the CFRP sheets from concrete surface.

Mostofinejad and Torabian [21] conducted experimentally research works on circular reinforcement concrete columns strengthened with longitudinal CFRP composites. They compared EBR and EBROG methods in their researches. Finally, the result demonstrated that in the columns strengthened with longitudinal FRP sheets using the EBROG method, improved the load-carrying capacity.

Mostofinejad and Akhlaghi [22] conducted a research on efficiency of grooving method in reinforcement beam-column joints that strengthened with CFRP sheets. The result showed using grooving method in this structure was able to eliminate altogether the debonding failure mode and remarkable improvement.

One of the fundamental problems in beams strengthened by FRP sheet is the premature failure that leads to sudden debonding of the sheets before reaching their ultimate strength. The main reason of this early failure is unsuitable surface preparation on beams that FRP composite is installed. Accordingly, preparation is needed to be done before connecting the FRP composite to WPC for eliminating poor surfaces and making an appropriate structure in FRP installation.

Among the failure modes, WPC delamination is one of the most prominent types of failure that increases the importance of further studies on this subject. The main goal of this research is to identify and provide a variety of methods of strengthening WPC and also choose the proper method to prevent sheets from debonding with considering of construction management.

In this regard, in addition to considering the resistance index, other indicators have also been considered. Schematic presentation of the processes of this study is illustrated in Figure 1.

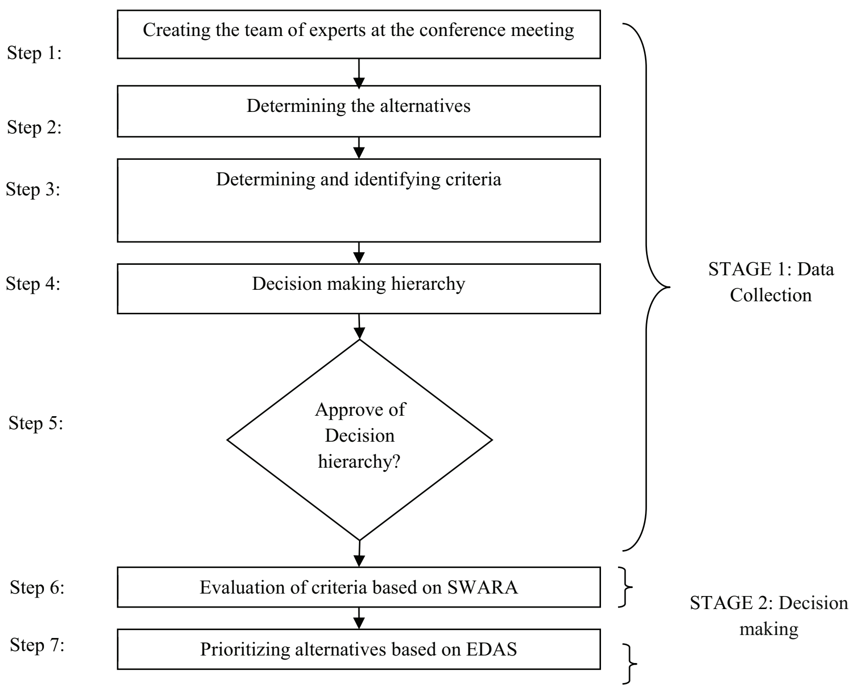

Fig. 1. Schematic presentation of WPC beam selection process

2. METHODOLOGY

In this study, first of all, literature review and references apply to evaluate various methods of strengthening WPC beams in order to prevent debonding of the FRP sheets. Then, all of the proposed criteria are extracted by interviewing experts in the field of construction management, structural engineering and economic experts to assess the best method of strengthening WPC beams (Table 1). Next, a questionnaire was presented to 21 experts to obtain their ideas in weighing effective criteria based on SWARA method; and finally alternatives will evaluate according to the EDAS methodology. SWARA-EDAS hybrid MADM method is a new-brand hybrid MADM method which is developed in this study as the main framework and methodology of the research. Juodagalvienė *et al.* [23] was the only case which applied SWARA-EDAS together for house's plan shape in practice. EDAS background will help to have more stable answers and SWARA like previous studies will be helpful in evaluating criteria based on policy based strategy and perspective.

Table 1. Background Information of Experts

Fields	Education Background	NO
Construction Management	Bachelor	-
	Master	3
	PhD	4
Economic	Bachelor	-
	Master	1
	PhD	-
Structural Engineer	Bachelor	-
	Master	5
	PhD	6
Top Managers	Bachelor	-
	Master	1
	PhD	1

2.1. SWARA METHOD

SWARA is a MADM method which is unique in its application. SWARA is useful to be applied for evaluating criteria and relative weights [24; 25]. Although SWARA is working the same as what AHP [26], ANP [27], FARE [28] and BWM [29] can do, the structure and perspective is almost different. SWARA is a policy based MADM method which is working based on priorities and policies in different levels of decision making process. In those cases which policies are in top of priority, SWARA method can be really helpful. For the first step as a SWARA methodology step, criteria should be ranked and prioritized based on policies and experts' opinions and this issue is special advantage of this method [30; 31].

Recently, SWARA has been applied in so many other studies such as:

- Assessing building projects regarding to environmental sustainability [32].
- Assessing process of chemical wastewater purification [33].
- Analyzing LARG supply chain management competitive strategies [34].

- Assessment of light supply in the public underground safe spaces [35].
- Evaluation of the vulnerability of office buildings [36].
- Personnel selection [37].
- Evaluating companies [38].
- Selection of green suppliers [39].
- Selection of candidates in the mining industry [40].
- Technology Foresight about R&D Projects Selection [41].
- Planning the priority of high tech industries [42].
- Structural health monitoring of bridges [43].

2.2. EDAS METHOD

This method has introduced recently and has an application the same as some older MADM methods such as: VIKOR, TOPSIS, COPRAS, and WASPAS etc. [44]. EDAS isn't the only new MADM method which is proposed in the new decade and some other such as WASPAS [45], CODAS [46] have introduced recently. The main idea of this new method it is not far from some other methods such as TOPSIS and VIKOR.

The main difference of EDAS is the answer of distance from average solution (AV) and main items are positive distance from average (PDA), and the negative distance from average (NDA). These items measures of differences of each alternative (solution or answer) and the average solution. Eventually, higher values of PDA and lower values of NDA will indicate optimal solution.

Recently, EDAS has been applied in so many other studies such as:

- Extended EDAS Based on Interval Grey Numbers [47].
- Evaluation of a Safe Built Environment due to Sustainable Development (SD) Values [48].
- An extended group EDAS [49].
- Group extended EDAS [50].
- Solid waste disposal site selection [51].

3. DETERMINE EFFECTIVE CRITERIA ON THE PROCESS OF SELECTION

Effective criteria were identified by doing interviews and getting ideas of experts to select strengthening methods by grooving; decision making criteria include a set of economic and administrative characteristics, which are presented in Table 2.

Table 2: Criteria influencing on strengthening WPC beam by grooving

Proposed indicators for evaluating different methods of strengthening by grooving		
C_1	Improving resistance	Max
C_2	Performance speed	Max
C_3	Performance complexity	Min
C_4	Performance costs	Min
C_5	Displacement	Min
C_6	Absorbing energy	Max

4. GROOVING METHODS ON REINFORCEMENT OF WPC-FRP BEAMS

There are five common grooving methods in reinforcement of WPC beams with FRP sheet as follows (Figure 2):

- Longitudinal groove (A1)
- Transverse groove (A2)
- Without surface preparation (A3)
- With surface preparation (A4)
- Diagonal groove (A5)

Longitudinal grooves are more resistant than other grooves because of the paralleled stress under the beam with longitudinal grooves and creating a proper surface between WPC surface and FRP sheet; it maximizes the strain of FRP sheets, and a beam with higher flexural capacity will be created. Strength of beams made by a diagonal groove is higher than the beams made by a transverse groove. Performance speed of longitude grooves is higher and it has less complexity than diagonal grooves, but it has less speed and higher complexity than the transverse grooves.

Considering the costs, the cost of the longitudinal groove is higher than transverse groove but it has a much lower cost comparing to the diagonal groove.

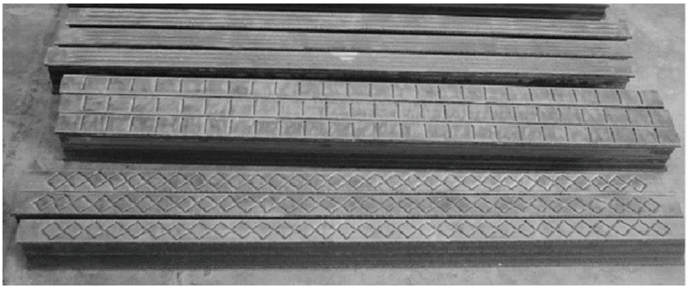

Fig. 2. Different shapes of grooves [13]

5. HIERARCHICAL TREE

The hierarchical tree is a graphical display of the issue (goal, criteria, and selecting options) (Figure 3).

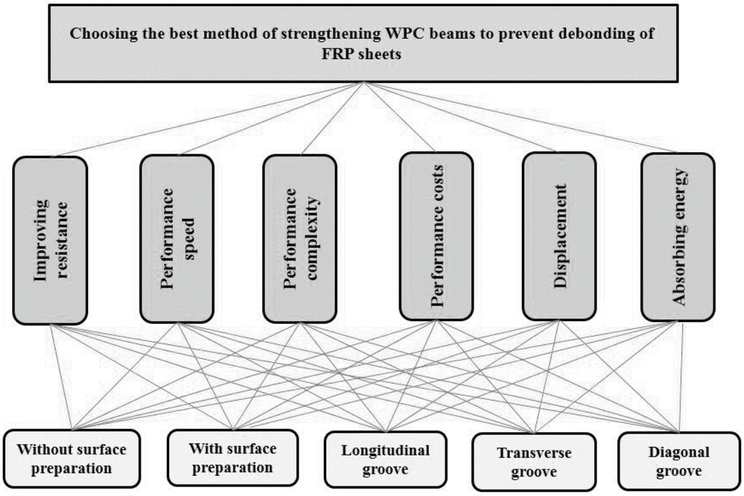

Fig. 3. Graphical hierarchy tree of selecting the optimal method of grooving

6. RESULTS FOR EVALUATING CRITERIA BASED ON SWARA

Due to methodology which is presented previously, calculations and final results for evaluating criteria are presented in Table 3. Based on methodological steps, this section has finished in 2 main steps. First of all, prioritizing criteria based on policies and eventually, the process of weighting.

Table 3. Criteria's evaluation based on SWARA method

Criterion	Comparative importance of average value s_j	Coefficient $k_j = s_j + 1$	Recalculated weight $w_j = \frac{x_{j-1}}{k_j}$	Weight $q_j = \frac{w_j}{\sum w_j}$
C_1		1	1	0.268
C_5	0.22	1.22	0.820	0.220
C_4	0.26	1.26	0.651	0.175
C_6	0.24	1.24	0.525	0.141
C_3	0.32	1.32	0.397	0.107
C_2	0.19	1.19	0.334	0.090

According to the results of SWARA method, improving resistance got the highest attention and weight and the priority for other criteria is as follows: displacement, performance costs, absorbing energy, performance complexity and performance speed.

7. RESULTS FOR EVALUATING CRITERIA BASED ON EDAS

Five probable solutions as alternatives are evaluated here, in this section, based on EDAS methodology. The process, information and final evaluation based on EDAS method is presented in table 4-9.

Table 4. Decision making matrix about strengthening WPC beams with grooving method

	C_1	C_2	C_3	C_4	C_5	C_6
Preferable	Max	Max	Min	Min	Min	Max
Weights	0.268	0.090	0.107	0.175	0.220	0.141
A_1	5.80	8	4	3	16.53	5
A_2	6.75	7	4	4	17.03	6
A_3	6.78	6	5	5	19.77	8
A_4	6.52	7	6	4	18.17	7
A_5	6.21	5	7	6	17.37	7

Table 5. Results for Positive Distance from Average (PDA)

	C_1	C_2	C_3	C_4	C_5	C_6
Weights	0.268	0.090	0.107	0.175	0.220	0.141
A_1	0.000	0.212	0.231	0.318	0.000	0.000
A_2	0.053	0.061	0.231	0.091	0.000	0.000
A_3	0.057	0.000	0.038	0.000	0.112	0.212
A_4	0.017	0.061	0.000	0.091	0.022	0.061
A_5	0.000	0.000	0.000	0.000	0.000	0.061

Table 6. Results for Negative Distance from Average (NDA)

	C_1	C_2	C_3	C_4	C_5	C_6
Weights	0.268	0.090	0.107	0.175	0.220	0.141
A_1	0.095	0.000	0.000	0.000	0.070	0.242
A_2	0.000	0.000	0.000	0.000	0.042	0.091
A_3	0.000	0.091	0.000	0.136	0.000	0.000
A_4	0.000	0.000	0.154	0.000	0.000	0.000
A_5	0.032	0.242	0.346	0.364	0.023	0.000

Table 7. Sum of Weighted PDA

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	0.000	0.047	0.040	0.045	0.000	0.000
A_2	0.014	0.013	0.040	0.013	0.000	0.000
A_3	0.015	0.000	0.007	0.000	0.012	0.019
A_4	0.005	0.013	0.000	0.013	0.002	0.005
A_5	0.000	0.000	0.000	0.000	0.000	0.005

Table 8. Sum of weighted NDA

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	0.026	0.000	0.000	0.000	0.007	0.022
A_2	0.000	0.000	0.000	0.000	0.004	0.008
A_3	0.000	0.020	0.000	0.019	0.000	0.000
A_4	0.000	0.000	0.027	0.000	0.000	0.000
A_5	0.008	0.053	0.061	0.051	0.002	0.000

Table 9. Normalized values (NSP, NSN) and ranking

	NSP	NSN	AS	Rank
A_1	1.000	0.688	0.844	1
A_2	0.612	0.928	0.770	2
A_3	0.404	0.777	0.590	3
A_4	0.292	0.847	0.569	4
A_5	0.041	0.000	0.021	5

According to the result which is extracted from table 10 and EDAS method, Longitude groove ranked as the best alternative and generally priority is as follows:

1. Longitude groove
2. Transverse groove
3. Without surface preparation
4. With surface preparation
5. Diagonal groove

8. CONCLUSION

As pointed out earlier, there are five common methods of grooving used to prevent debonding of FPR in WPC beams. To evaluate this method of grooving, six criteria were considered according to experts' ideas. In this research, as it mentioned, 21 experts participated in the process of research which covered both sides of methodologies and results.

SWARA as a policy based MADM method, applied for evaluating criteria and weighting them. From the outputs of SWARA method, more important policies and decisions illustrated as follows: improving resistance considered as the most critical and important criterion for evaluating alternatives. After that, displacement, performance cost, absorbing energy, performance complexity and performance speed placed as the policies (decisions) in their priority.

Grooving methods as alternatives for this decision making challenge evaluated by EDAS method which is a new brand MADM method. Based on results all five alternatives prioritized and ranked as follows: 1. Longitude groove; 2. Transverse groove; 3. Without surface preparation; 4. With surface preparation; 5. Diagonal groove.

As it presented in this article, another contribution of this study was presenting new hybrid MADM method which is completely practical and user friendly for managers and policy makers. SWARA-EDAS can be applied in other research studies in the future when researchers need an area to consider more policies instead of just classical decision making system and moderate-conservative and reliable answers.

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