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Analysis of Alternative Protective Materials Against Mechanical Impacts for a New Generation Goalkeeper Jersey

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ABSTRACT

The physical characteristics of the jerseys utilized by football (soccer) goalkeepers are crucial for the comfort of the players to perform the related activities. This study aims to investigate various materials, to facilitate the examination and development of new-generation goalkeeper jerseys that differentiate from the jerseys used currently. Within the scope of the study materials that are functionally better (such as less impact, and higher resilience) than sponge material were investigated. Corresponding tests (penetration depth, surface stiffness, bending strength, resilience, mass per unit area, thickness, and sewability) were carried out for analysing the functionality of these alternative materials. The test results of these alternative materials were compared with the values obtained from the sponges that are used widely in today's goalkeeper jerseys. In light of the data resulting from the research and experiments, the materials of 5mm EPDM and/or 5mm Neoprene used in the jerseys provided better protection properties against mechanical effects together with ensuring better functionality compared to the sponge material.

KEYWORDS

clothing, sport science, sports clothes, protective material, goalkeeper jersey

INTRODUCTION

Injuries are common in football like in every type of sports activity. This impacts negatively both the health of players and the total performance of the teams [1-3]. To minimize the risk of injury, functional textile products are developed and used with the help of various technical textiles [4]. According to the Federation Internationale de Football Association (FIFA), goalkeepers can use jerseys with protection against mechanical impact to be able to protect them from ground impacts [5].

In two separate studies conducted in Sweden, the types of disability experienced by the goalkeepers were expressed regionally in percentages. The necessity of improvements of the goalkeeper clothes was emphasized in these studies [6,7]. The book "Materials in Sports Equipment", underlines that the thickness of materials such as shock-absorbing foam, sponge, mat, and the ability of shock absorption is in direct relation with each other [8]. In two studies, it was emphasized that sports clothes should be improved to prevent injuries in different types of sports. The previous studies in the literature emphasized the importance of the future developments of apparel products used in football (soccer). However, a final version of a concrete product related to football jerseys was not obtained within the scope of these studies [2,9]. In the study by Sherwood and Drane, the use of "shock-absorbing memory foam", which has been known as the most modern method for protecting the chest area of ball catchers in baseball games, was pointed out. This research utilizes memory foam as one of the materials to be tested. In a study conducted in Switzerland, the frequency of exposed impacts occurred resulting from the falling movements of the goalkeepers was measured considering only the hip area. In this study, protective jerseys like padded shorts and shirts are recommended to goalkeepers by FIFA [10]. However, product development stages were not conducted in the study. In a study conducted in Sweden, injuries in the shoulder areas that were caused by the fall of the goalkeepers were addressed [11]. Goalkeepers had a significantly higher incidence of upper-extremity injuries compared to other players. According to research data, of all injuries registered among them, 18% affected the upper extremities and its prevalence per season was consistently higher among goalkeepers than others [12]. In a study related to the football industry by Li and Jiao in 2019, the injury risk factors affecting the frequency of injury were monitored. The current situation and characteristics of injury in football were analyzed, and wearing appropriate protective clothes becoming indispensable to most sportsmen was suggested [13].

The task of goalkeepers in all sports is to protect the goal areas by not allowing the balls sent by the opponent to pass into their protection areas. As a result of the ball being sent by the opponent as quickly as possible and/or to the parts of the goal that are difficult to reach, the goalkeeper must catch up with the action called jumping or flying to respond to these balls. The movements such as jumping, flying, lying down, crawling, etc. that the goalkeepers have to do due to their position in the team might cause severe effects on their bodies. One of the tasks of goalkeeper jerseys is to reduce the impact energy transferred from the ground to the body parts due to the fall on the ground.

The research aims to investigate the existing goalkeeper jerseys in the football (soccer) market, which are supported only with a sponge to protect players from the ground impacts caused by their movements (jumping, jumping, etc.), and provide a comparison with the alternative materials. Considering these facts, in this study, the materials that can be used instead of the sponge were determined and 7 different tests (impact absorption, surface stiffness, bending strength, resilience, weight, thickness, and sewability) were applied to these materials and sponge. While a ready-made product was functionalized, all physical properties were intended to be checked. For this reason, these 7 tests were chosen to highlight these properties. Finally, the values obtained were compared and evaluated to find out the most appropriate material that can be used instead of sponges. Based on the findings, the materials with better results demonstrated better functionality and support to professional goalkeepers and goalkeeper candidates, especially those playing in lower-aged teams.

MATERIAL AND METHOD

Materials

Today, according to market research conducted among well-known brands, the sponge is frequently used as a protective material in the elbow, hip, and chest areas of all goalkeeper jerseys by having the same thickness in each of these areas (Figure 1).

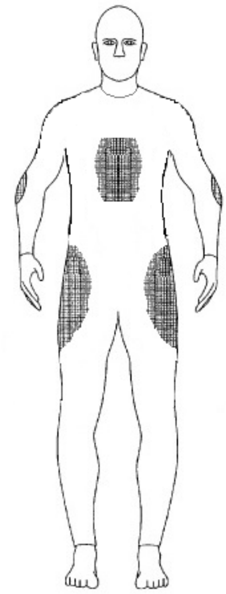

Figure 1. Protected areas of the goalkeeper jersey in the market

Although the main raw material of the sponge is latex since natural latex could not meet the sponge demand in the market, scientists succeeded in creating polyurethane raw material in 1937 and then, the sponge has been comprised mainly of polyurethane (Figure 1). Sponges are measured in terms of density in kg/m^3 and this becomes one of their most important features affecting their durability and support strength. It should be noted that high-density sponges retain their properties longer.

The sponge material used in goalkeeper jerseys has a density of 24 or 26 and the cell count (pores in their structures) is 40-43 (± 5) number/inch, resulting from the examinations made in the jerseys of well-known sports brands. It was decided to include only D24 in all tests between the D24 and D26 sponges which are widely used in the existing goalkeeper jerseys and have similar properties.

In the scope of this study, alternative materials that are effective in preventing impact transmission have been investigated, and accordingly, various tests have been performed on these materials. Finally, the results have been compared with the sponge material currently used in the market.

The protective materials considered to have better properties than the sponges in the market are listed as follows;

- EVA (EtilenVinilAsetat): This material is produced within the copolymerization of ethylene and vinyl acetate. EVA is a material that has durability, flexibility, and lightness. It has high flexibility properties. In this study, 3 mm, 5 mm, and 10 mm thickness varieties of EVA material were included in the tests (Figure 2).

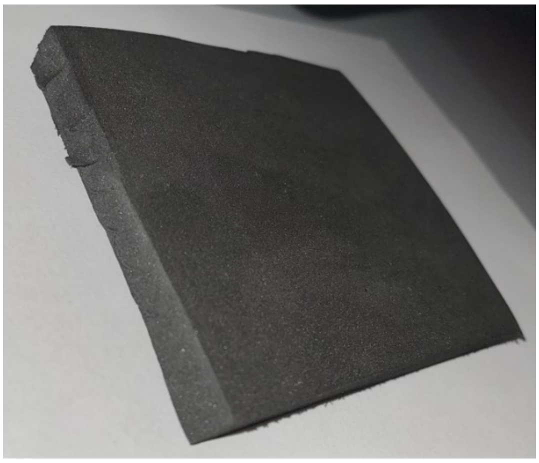

Figure 2. EVA material with different thicknesses

- EPDM (EtilenPropilenDien Monomer): EPDM is generally preferred for impact-resistant materials. It has a low density as a material. This material shows high performance in terms of elasticity and resistance to permanent deformation. Today, it is used in products such as gym floor covering, etc. In this study, 3 mm, 5 mm, and 10 mm thickness varieties of EPDM material were included in the tests (Figure 3).

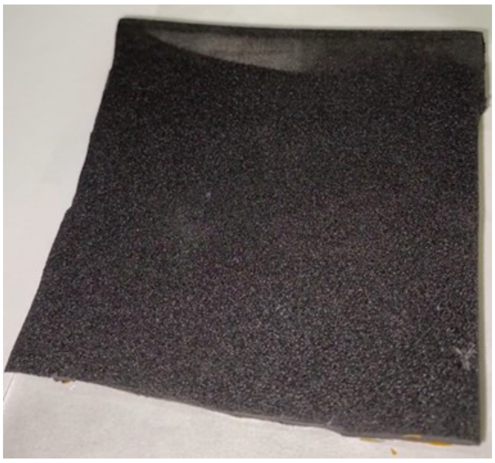

Figure 3. EPDM material

- Neoprene: Neoprene, which was named duprene when it was invented in 1930 in the laboratories of Dupont, was the first artificial rubber-type material produced in large quantities. Today, it is used in products such as inflatable boats and diving suits. In this study, 3 mm, 5 mm, and 10 mm thickness varieties of neoprene material were included in the tests (Figure 4).

Figure 4. Neoprene material

- Memory Foam: Memory foam, also known as memory sponge or smart sponge, is a technology developed by the American Space Research Agency (NASA) in the 1960s to reduce the load and pressure on the spine of astronauts during their travel. In this study, 3 mm, 5 mm, 8 mm, 10 mm, 13 mm, and 15 mm thickness varieties of memory foam material were included in the tests (Figure 5).

Figure 5. Memory foam material

- 3D Spacer Fabrics: These kinds of surfaces are called “Spacers” in the international literature, but they are also described by different names in the market. Spacer surfaces are obtained by interconnecting two different surfaces produced through the double-face technique in interlock machines with monofilament yarn. These fabrics, made of 100% polyester, are used in areas such as automotive textiles, medical textiles, geo-textiles and protective textiles, given their flexible and three-dimensional structure. Recently, it has started to be in demand in sportswear, outerwear, and underwear. These fabrics have pressure reduction and shock absorption properties. As shown in Figure 6, thanks to the springiness effect, it absorbs the energy during impacts, such as strike and hit, and protects it from the damaging effect of the impact. For the spacer samples to be tested in this study, it was decided to include the 5 most suitable spacers in the experiments. Throughout the study, these samples will be referred to as spacer-1, spacer-2, spacer-3, spacer-4, and spacer-5.

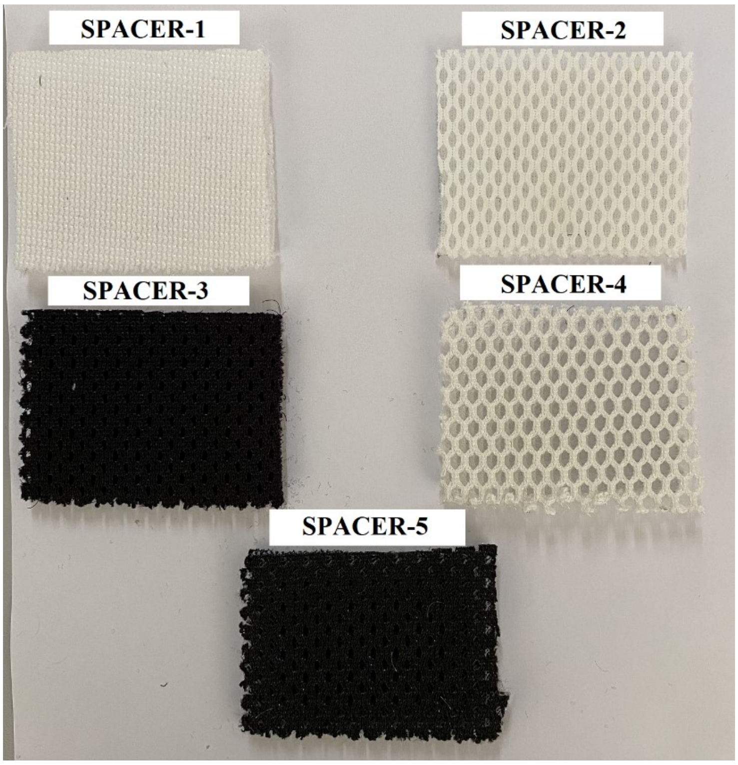

Figure 6. Spacer (sandwich) fabric sample

The properties of the spacers that are provided are shown in the following table (Table 1).

Table 1. Properties of the spacer fabrics

Sample	Construction	Material	Thickness (mm)
Spacer-1	Two surfaces closed	%100 PES	7
Spacer-2	One surface with hole, other surface closed	%100 PES	3.5
Spacer-3	One surface with hole, other surface closed	%100 PES	5.5
Spacer-4	Two surfaces with the hole	%100 PES	8
Spacer-5	Two surfaces with the hole	%100 PES	6.25

Thus, including the different thicknesses of 6 different materials, a total of 21 different materials were included within the scope of the experiment plan and evaluated with the tests specified in the method section.

Methods

The tests planned for the materials are shown below. Owing to the data obtained from the tests, the materials were compared with the sponge material currently used in the jerseys. After the tests and evaluations, the most suitable material was chosen with the decision-making methods of AHP (Analytic Hierarchy Process) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution).

a. *Material Impact Test:* The penetration depth properties of the materials were tested by the impact test *device*. This test instrument works based on the principle of dropping a mass on the materials to be tested in its chamber. This device measures the ability of the materials to reduce the effect of the mass. In the impact tests of the materials, the strike energy of 15 J was used. The data obtained as a result of the test indicates the amount of collapse caused by the falling weight on the tested material and the amount of swelling on the back surface. In this direction, it determines in mm how much the material transfers the incoming impact to the other surface. This test was carried out following the Standard of VPAM KDIV 2004 (Vereinigung der PrüfstellenfürangriffshemmendeMaterialien und Konstruktionen) (Stab and Impact Resistant) [14]. The results obtained were interpreted as "the smallest value is the best". Although the results generated by the test are in mm, it allows the decision makers to draw a conclusion and do comparisons in terms of impact. An impactor is an object with edges (block). The size of the tested sample is 20x20 cm.

b. *Surface Hardness Test → Durometer:* The surface stiffness of the material to be used instead of the sponge is expected to be as close to the stiffness of the sponge as possible. A durometer is a device developed to measure the stiffness of the materials such as rubber, plastic, elastic materials, textile, printing rolls, etc. Type A Durometer was used to carry out the tests in this study. The tests were carried out following the standard of ASTM D 2240 [15]. The results obtained were interpreted as "the least stiff (the smallest value) is the best".

c. *Grammage Test → Circular fabric cutting device, precision scales:* The device is used to measure the square meter weight of textile surfaces. This test was carried out following the standard of TS EN 12127 [16].

d. *Thickness Test → Ultrasound thickness meter PCE-TG110*: With this device, the thickness of glass, plastic and other homogeneous materials are determined. This test was carried out following the standard of TS 7128 EN ISO 5084 [17].

e. *Sewability Test → The L+M Sewability Tester:* The sewability testing device tests the degree of sewability of folded fabrics or surfaces with two different properties by a sewing machine without damaging the machine, machine parts and the surfaces to be sewn [18].

f. *Bending Strength Test:* The bending strength test result is the indicator of the resistance of the surfaces against bending stress [19]. The bending strength test was carried out in the Zwick Roell test device following the ASTM D790 standard [20]. The value obtained from the tests indicates the bending resistance value of the material and the least resistant material means it is the most flexible material tested. For this reason, results obtained from this test were interpreted as "the smallest is the best".
g. *Resilience Test:* One of the criteria that determine the lifetime of a surface is its compression and reversibility (resilience) feature. This feature can be tested with a meter that provides a static and dynamic load on the surface. The tests were carried out following the ISO 2094: 1999 standard with "Wira Digital Thickness Gauge" [21]. The values obtained from this test provide the percentage ratio of the difference between the first length and the last length, meaning that the material with the smallest value has the best resilience property.

Each type of test, conducted on the alternative materials over the sponge evaluated within the scope of the study, was considered as a criterion. It is important to note that, not every material can achieve equal success on every criterion basis (each test assumes as a criterion). However, it is a requirement that the material to be used in the jersey carries each specified criterion to a certain extent. For example, there is a need for different selection instruments arises when choosing between a material with a high resilience-low sewability and a material with high thickness-low flexibility. At this point, it is necessary to give importance weights to each criterion to enable the comparisons to obtain consistent and logical results. AHP technique was used to determine the importance weights of each test (criterion). After weights were determined, these weights were used in the TOPSIS method and the most appropriate material was sorted.

Method of AHP

When looking at the steps to be followed in AHP theory, first of all, the goal of a problem and the criteria to define this goal should be determined. Then, to create a hierarchical structure that includes the main goal and all of the criteria related and to determine the criteria weights, the pairwise comparison matrix should be constructed in the “nxn” dimension. After the hierarchical structure of the problem has been defined, the stage of pairwise comparisons of the criteria at the same levels follows[22]. The scale of 1-9, developed by Saaty, was used in the creation of pairwise comparison judgments between criteria and alternatives (Table 2) [23].

Table 2. The pairwise comparison

Criteria	Score																	Criteria
Penetration depth	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Thickness
Penetration depth	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Sewability
Surface stiffness	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Bending strength

According to this comparison shown in Table 2, when the decision maker chooses the score on the side that is closer to the criterion, that criterion becomes of higher importance than the other one. Decision makers were informed about this issue and were requested to give their answers accordingly.

Although AHP has a consistent system in itself, the results as the outcome of it are based on personal evaluations of the decision-makers. Therefore, it is necessary to check whether the comparisons made by the decision-makers are consistent considering the whole hierarchy. This is determined via the "Consistency Rate (CR)". AHP provides the measurement of consistency in every judgment step. The consistency ratio is calculated for each pairwise comparison matrix, and the upper limit is required to be 0.10 for this ratio. If the rate is above 0.10, it means that there is an inconsistency in the judgments of the decision maker [24]. In the determination of the weights of the criteria, a decision group including 10 people from different disciplines related to the subject (2 professional goalkeepers, 3 professors from textile engineering sciences, 3 professors from sports sciences, and 2-managers from the clothing industry) were subjected to pairwise comparisons through a survey within the scope of AHP. As a result of all the answers, the weights of the criteria were determined. The consistency ratios of all decision-makers are as follows (Table 3).

Table 3. The consistency ratios of decision-makers

Decision makers	CR
1.	0.0281
2.	0.0012
3.	0.0034
4.	0.0025
5.	0.0031
6.	0.0021
7.	0.0027
8.	0.0067
9.	0.0127
10.	0.0891

Method of TOPSIS

Another method to be used in the study was the TOPSIS technique. Based on the data obtained from all of the tests mentioned above and the criteria weights determined by the AHP method, the TOPSIS technique was used to determine the most suitable material for use. This technique consists of 6 steps and the steps are as follows [25-27].

Step-1: Decision matrix construction; firstly, the decision matrix is prepared.

Step-2: Normalized decision matrix construction; the normalized value rij of the i alternative in the decision matrix according to the j criterion is calculated with the following formula (1).

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^{m} f_{ij}^2}} \quad j=1,2,3,...m; \quad i=1,2,3,...n \qquad (1)$$

Step-3: Weighted normalized decision matrix construction; The weighted normalized value v_{ij} is calculated with the following formula (2) (The value of w_i represents the weight of the i. criterion).

$$v_{ij} = w_i \times rj=1,2,3,...m; \quad i=1,2,3,...n \qquad (2)$$

Step-4: Calculating the ideal (A^*) and the negative ideal (A^-) solutions are calculated as follows.

$$A^* = \{v_1^* ..., v_n^*\} = <(max_j v_{ij} \mid i \in I'), (min_j v_{ij} \mid i \in I'')> \qquad (3)$$

$$A^- = \{v_1^- ..., vn^-\} = <(min_j v_{ij} \mid i \in I'), (max_j v_{ij} \mid i \in I'')> \qquad (4)$$

Step-5: Calculating the distance of each alternative to the positive and negative ideal solution; The measure, which indicates the distance of each alternative from the positive ideal solution, is calculated with the following formula (5) (6).

$$S_i^* = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_j^*)^2} \qquad (5)$$

$$S_i^- = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_j^-)^2} \qquad (6)$$

Step-6: Calculating the relative proximity and ranking of the alternatives; the relative closeness of the alternative a_i to A^* is calculated by the following formula (7) [25-27].

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \quad (7)$$

RESULTS AND DISCUSSION

The test results, obtained by performing all the tests conducted on the materials mentioned in the method section, are shown below (Table 4).

Table 4. Test results of the materials

Materials	Penetration depth (mm)	Surface stiffness (duro)	Bending strength (newton)	Resilience (%)	Mass per unit area (g/m²)	Thickness (mm)	Sewability value
Current sponge in use							
5 mm (24 density)	29.3	3.4	0.00394	52.99	210	5	3
EVA							
3 mm	23.6	35.5	0.02284	8.14	300	3	5
5 mm	20.1	38.5	0.04474	12.05	570	5	9
10 mm	11.7	25	0.575	2.96	612	10	24
EPDM							
3 mm	21.8	19.5	0.01546	3.1	310	3	0
5 mm	21.6	14.5	0.04202	3.22	490	5	0
10 mm	19.1	13.5	0.2852	3.36	864	10	13
Neoprene							
3 mm	25	9.1	0.00352	8.07	350	3	0
5 mm	24.4	9.2	0.00631	6.01	475	5	0
10 mm	23.1	10.4	0.01322	13.76	870	10	11
Memory foam							
3 mm	26.9	4.5	0.00184	34.72	106	3	0
5 mm	26.1	3	0.00317	35.74	180	5	3
8 mm	27.4	1.5	0.00589	33.57	249	8	4
10 mm	25.1	1	0.00591	31.95	358	10	6
13 mm	25.1	1	0.00853	27.63	434	13	11
15 mm	24.8	1	0.01448	20.36	508	15	13
Spacer fabrics							
Spacer-1	25	12	0.02056	9.58	600	7	11
Spacer-2	24	13	0.00582	8.48	330	3.5	10
Spacer-3	22.6	15	0.0199	7.65	680	5.5	9
Spacer-4	24.5	16	0.00654	11.78	400	8	14
Spacer-5	23.1	18	0.01129	8.63	780	6.25	11

In addition to the test results obtained, the relative importance weight of each criterion must be calculated to determine the most suitable material that can be used for the study. Thanks to the pairwise comparisons based on expert opinions, the relative importance of the criteria were determined and their arithmetic averages were taken accordingly. The criteria weights obtained are shown below (Table 5).

Table 5. Material selection criteria and their relative weights

Criteria	Relative weights
Impact behaviour	0.310
Surface hardness	0.113
Bending strength	0.153
Resilience	0.1
Grammage	0.074
Thickness	0.111
Sewability	0.135

The criteria weights of each criterion were obtained as a result of pairwise comparisons, so each criterion affected the result in terms of its weight, as shown in TOPSIS step 3 (formula no.2). Accordingly, the criteria weights shown in Table 5 were included in the matrices used in the TOPSIS method, and the results were evaluated accordingly.

When the Consistency Rate (CR values) obtained to test the reliability of the evaluations were considered, it is possible to state that the data used in the methods are valid since the comparisons of the 10 respondents meet the $CR < 0.10$ condition.

The data obtained by performing all the tests included in the study are shown in Table 4. In the statistical evaluation of these data, the application steps of the TOPSIS method were applied respectively. Accordingly, the most suitable material ranking was made by considering the distance of the alternatives to the ideal solution. As a result of optimizing the data obtained from the material tests, the material order with the value closest to the ideal solution is listed in the table below (Table 6, Figure 7).

Table 6. Ranking of the materials based on their suitability for the purpose

Ranking	Material	Ci
1	EPDM-5mm	0,8110393
2	Neoprene-5mm	0,8090836
3	Neoprene-3mm	0,8085509
4	Memory-3mm	0,8085600
5	EPDM-3mm	0,8057878
6	Spacer-2	0,7661683
7	Spacer-3	0,761527
8	Memory-5mm	0,7543775

Ranking	Material	Ci
9	Memory-10mm	0,7417583
10	Memory-8mm	0,7380977
11	Spacer-1	0,7342847
12	Spacer-5	0,7318114
13	Neoprene-10mm	0,7264769
14	Eva-3mm	0,7105882
15	Spacer-4	0,7104246
16	Memory-13mm	0,7067232
17	Sponge	0,6935051
18	Memory-15mm	0,6920422
19	Eva-5mm	0,6793475
20	EPDM-10mm	0,5457401
21	Eva-10mm	0,3249784

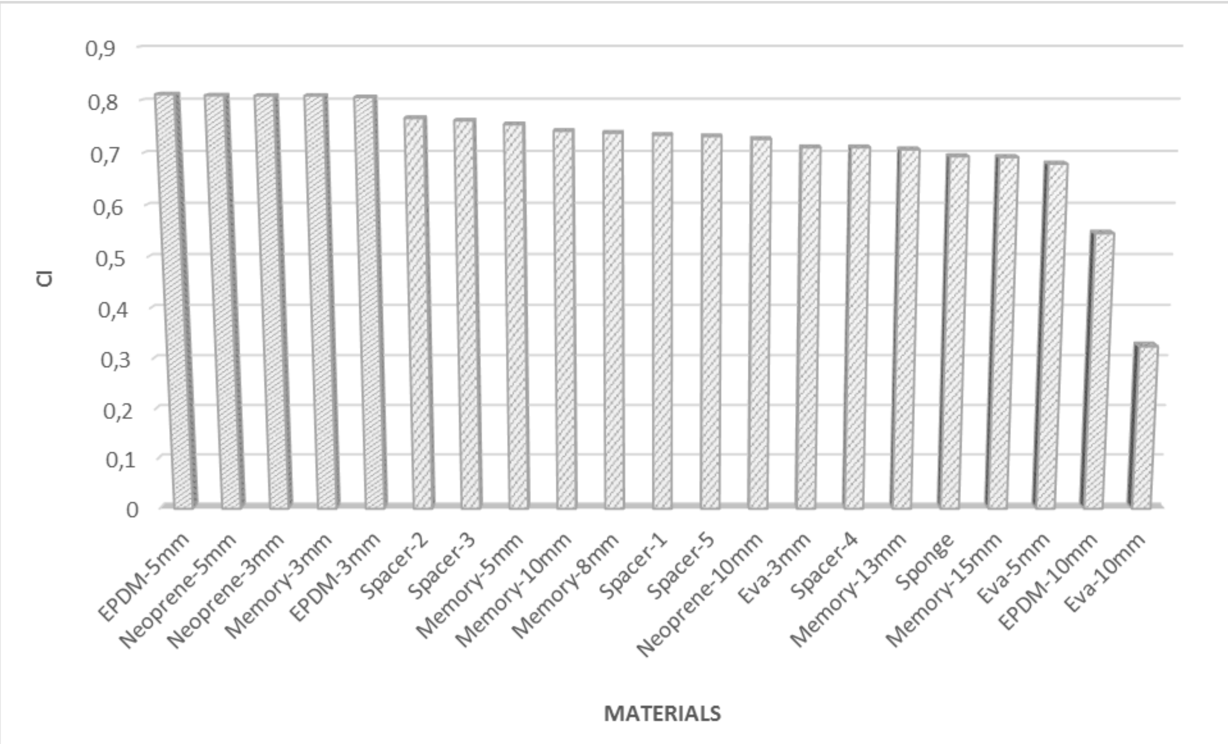

Figure 7. Ranking of the materials based on their suitability for the purpose

According to tests and evaluations, the most suitable material has been EPDM 5 mm, while Neoprene-5mm becomes the second most suitable material. On the other hand, the sponge used in the current goalkeeper jerseys ranks 17th among other alternative materials based on the same evaluations.

CONCLUSION

The design of apparel products used in football is one of the most important factors that play a role in performing this sport professionally and comfortably. Football requires the player to move actively. For this reason, the apparel products used should be well designed and manufactured to keep up with these active sports movements, protect the athlete when necessary, and they should also prevent distraction by focusing on factors (about clothing) other than sports.

In the light of the data resulting from the research and experiments within the scope of this study, the materials of 5 mm EPDM and/or 5 mm Neoprene provided better results in terms of penetration depth, surface hardness, bending strength, resistance, grammage, thickness, and sewability tests compared to sponge material which is widely used in the current jerseys. In this regard, the effects of the determining criteria on the physical properties are stated as follows;

- An increase in the material thickness has a positive impact on the penetration depth, whereas it has a negative effect on the sewability properties of the materials.
- The resilience properties of all the alternative materials included in the tests give better results than the sponge material.
- The penetration depth, resistance and sewability values of the 5 mm EPDM material provides the most appropriate results for its intended use, compared to the sponge used in the existing jerseys. However, better results are obtained from sponge material than EPDM-5 mm in terms of surface hardness, bending strength, and grammage tests. It is also important to emphasize that the weight coefficients of each test (criterion) determined within the scope of AHP play an important role in determining the EPDM-5 mm material as being more suitable for goalkeeper jerseys.

The materials tested in the scope of the study and the test results proved that they are likely to serve as a model for other sports branches such as handball, baseball, ice hockey, etc. where goalkeepers are needed.

Based on the experiments and analysis, it is essential to indicate that the materials of EPDM-5mm and Neoprene-5mm provide preferred results for a physical evaluation. In addition to this, the fitting results of the presented materials and the alternative usages in various types of clothing items will be shared in the following studies.

Author contributions

Conceptualization – Kucuk M and Güner M; methodology – Kucuk M and Güner M; formal analysis – Kucuk M; investigation – Kucuk M; writing-original draft preparation – Kucuk M; writing-review and editing – Kucuk M and Güner M; visualization – Kucuk M. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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REFERENCES

[1] Lohkamp M, Kromer TO, Schmitt H. Osteoarthritis and joint replacements of the lower limb and spine in ex-professional soccer players: a systematic review. Scandinavian Journal of Medicine & Science in Sports. 2017; 27(10):1038-1049. https://doi.org/10.1111/sms.12846

[2] Windt J, Ekstrand J, Khan KM, McCall A, Zumbo BD. Does player unavailability affect football teams match physical outputs? A two-season study of the UEFA champions league. The Journal of Science and Medicine in Sport. 2017. https://doi.org/10.1016/j.jsams.2017.08.007

[3] O'Brien J, Finch C F, Pruna R, McCall A. A new model for injury prevention in team sports: the Team-sport Injury Prevention (TIP) cycle. Science and Medicine in Football. 2019; 3(1):77-80. https://doi.org/10.1080/24733938.2018.1512752

[4] Mandal S, Annaheim S, Camenzind M, Rossi RM. Personal protective textiles and clothing. In: Roshan P, editor. High performance technical textiles. John Wiley & Sons, 2019. p. 159-195. https://doi.org/10.1002/9781119325062.ch6

[5] FIFA (Federation Internationale de Football Association). 2021/2022. Equipment Regulations. Available from: https://digitalhub.fifa.com/m/4028a792bb93a722/original/q3drmdesvc8bbmanff8d-pdf.pdf

[6] Chomiak J, Junge A, Peterson L, Dvorak J. Severe injuries in football players influencing factors. The American Journal of Sports Medicine. 2000; 28(5):58-68.

[7] Injury prevention: Goalkeeper warm-up programme. 2022. Available from: https://www.fifa.com/en/about-fifa/medical/injury-prevention

[8] Jenkins M. Materials in sports equipment. Woodhead Publishing Limited; 2003.

[9] Arnason A. Injuries in Football - Risk factors, injury mechanisms, team performance and prevention [dissertation]. Oslo: Oslo Sports Trauma Research Center, Norwegian University of Sport and Physical Education; 2004.

[10] Schmitt KU, Schlittler M, Boesiger P. Biomechanical loading of the hip during side jumps by soccer goalkeepers. Journal of Sports Sciences. 2010; 28(1):53-59.

[11] Ekstrand J, Hagglund M, Walden M. Injury incidence and injury patterns in professional football-the UEFA injury study. British Journal of Sports Medicine. 2011; 45:553-558.

[12] Sevivas N, Karahan M, Vilela C, Cartucho A. Overuse injuries of the goalkeeper. In: van Dijk C, Neyret P, Cohen M, Della Villa S, Pereira H, Oliveira J, editors. Injuries and Health Problems in Football. Berlin: Springer; 2007. p. 353-361. https://doi.org/10.1007/978-3-662-53924-8_31

[13] Li L, Jiao Z. Injury detection and protection method based on human body structure analysis. Investigacion Clinica. 2019; 60(1):48-58.

[14] VPAM (Vereinigung der Prüfstellen für angriffshemmende Materialienund Konstruktionen). Stab and impact resistance requirements, classifications and test procedures. 2021. Available from: https://www.vpam.eu/pruefrichtlinien/aktuell/apr-2006/.

[15] ASTM D 2240. Durometer hardness shore hardness. 2021. Available from: https://www.astm.org/d2240-15r21.html

[16] TS EN 12127. Textiles – fabrics - determination of mass per unit area using small samples. 1998. Available from: https://www.en-standard.eu/bs-en-12127-1998-textiles-fabrics-determination-of-mass-per-unit-area-using-small-samples/

[17] TS 7128 EN ISO 5084. Textiles-determination of thickness of textiles and textile products. 1998. Available from: https://intweb.tse.org.tr/standard/standard/Standard.aspx?081118051115108051104119110104055047105102120088111043113104073086114117097101088070078109052076

[18] Ondogan Z, Utkun E, Pamuk O, Yıldız E. Sewability in Apparel Industry. In: The Fourth Edition of the International Conference of Applied Research in Textile (CIRAT-4) Monastir, Tunisia. 2010.

[19] Özdil N. Physical quality control methods in fabrics in English. Ege University Research and Application Center of Textile and Apparel Manufacturing, 2003. 21 p.

[20] ASTM D790. Flexure testing of plastics. 2017. Available from: https://www.astm.org/d0790-17.html

[21] ISO 2094:1999. Textile floor coverings. Determination of thickness loss under dynamic loading. 1999. Available from: https://www.iso.org/standard/30505.html

[22] Saaty TL. How to make a decision: the analytic hierarchy process. European Journal of Operational Research. 1990; 48:9-26.

[23] Saaty TL, Tran LT. On the invalidity of fuzzifying numerical judgments in the analytic hierarchy process. Mathematical and Computer Modelling. 2007; 46:962–975.

[24] Donegan HA, Dodd FJ, McMaster TB. A new approach to AHP decision-making. The Statistician. 1992; 41:295-302.

[25] Dymova L, Sevastjanov P, Tikhonenko A. A direct interval extension of TOPSIS method. Expert Systems with Applications. 2013; 40:4841-4847.

[26] Zhang X, Zhang Q, Sun T, Zou Y, Chen H. Evaluation of urban public transport priority performance based on the improved TOPSIS method: A case study of Wuhan. Sustainable Cities and Society. 2018; 43:357-365. https://doi.org/10.1016/j.scs.2018.08.013

[27] Chakraborty S. TOPSIS and Modified TOPSIS: A comparative analysis. Decision Analytics Journal. 2022; 2:100021. https://doi.org/10.1016/j.dajour.2021.100021