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Recycled Materials in the Development of Shin Guards for *Sepak Raga Tuju*: A Green Innovation Supporting the Sustainable Development Agenda (SDG 9 and SDG 12)

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Abstract. Awareness of sustainability in sports product design is increasing, especially through the use of recycled materials to reduce environmental impact. This study aimed to design and develop an eco-friendly foot protection prototype for the traditional sport of Sepak Raga Tuju, by integrating green innovation in the local context. The development process involved the use of readily available waste materials such as insulation pipes and polyethylene foam, which were selected for their lightweight and environmentally friendly properties. The study methods included product design and fabrication, material composition analysis using Fourier Transform Infrared Spectroscopy (FTIR), and evaluation of mechanical properties through ASTM D638 Tensile Testing. In addition, user acceptance evaluation was also conducted through the distribution of questionnaires to players and coaches. The FTIR test results confirmed the presence of the characteristic chemical structure of polyethylene, while the mechanical test showed a maximum elongation of 80.2% and a breaking stress of 0.219 MPa, which reflects the basic shock absorption capacity. Overall, the prototype demonstrated adequate basic protection functions while contributing to the reduction of material waste. This study supports the Sustainable Development Goals (SDG 9 and SDG 12) and offers an innovative approach that combines aspects of sports safety, environmental sustainability and the economic value of recycling in the development of traditional sports equipment.

Keywords: Green Innovation, Shin Guards, *Sepak Raga Tuju*, Sustainable Development, Design

1. INTRODUCTION

Sepak Raga Tuju is one of the traditional sports in Malaysia that is still practiced today as an effort to preserve cultural heritage and strengthen the identity of the local community. Apart from being a recreational activity, this sport also reflects the values of agility, teamwork and social unity among players. It also serves as a cultural heritage that is passed down from generation to generation, thus strengthening the identity of the community. The active involvement of this sport in various community events and celebrations proves its significant role in maintaining the country's traditional sports culture [1].

Despite its high cultural importance, the safety aspect of players, especially those involving the shins and ankles is often given little attention. Injuries such as strains and contusions often occur due to intensive movement and the lack of protective equipment designed specifically for this sport [2]. Most of the foot protectors available on the market today are designed for modern sports such as football and are made of synthetic materials. Although capable of providing protection, the use of these synthetic materials involves high costs, relies on non-renewable resources, and creates environmental pollution problems because they are difficult to dispose of and are not easily recycled [3].

This situation highlights the need for innovative solutions that can simultaneously address safety and sustainability issues. Accordingly, this study explores the use of recycled materials specifically insulation pipes and polyethylene foam as the main materials in the development of a prototype foot protector for the sport of Sepak Raga

Tuju. This approach not only improves player protection but also reduces negative impacts on the environment. This initiative is in line with the principles of the circular economy and supports the Sustainable Development Goals (SDGs), specifically SDG 9 (Industry, Innovation and Infrastructure) and SDG 12 (Responsible Consumption and Production) [4].

The scope of this study covers the design and development process of a green foot protector prototype, including material selection, laboratory testing of mechanical and chemical properties, and user evaluation in terms of comfort, effectiveness and cost-efficiency. The main objective of the study is to produce sustainable and practical foot protector innovations, especially for use by school students and Technical and Vocational Training (TVET) institutions. By integrating social, economic and environmental aspects at every stage of design to final production, this study aims to contribute to improving safety in traditional sports while fostering awareness of green innovation in sports equipment manufacturing. Overall, this innovation is expected to enhance the user experience, support the preservation of cultural heritage and promote the development of more environmentally friendly products.

2. LITERATURE REVIEW

2.1 Traditional Sports and the Need for Protective Equipment

Literature review shows that traditional sports such as Sepak Raga Tuju have a high risk of injury, especially to the legs such as the shins and ankles. This risk is usually caused by collisions in the playing area and repeated impacts experienced by players [5]. In modern sports, the use of protectors such as shin guards is a common practice to reduce the risk of injury. However, specific studies on protectors for traditional sports are still very limited, indicating that the aspect of protection in the context of this sport is not given enough attention [6]. The literature on sports equipment emphasizes the importance of protectors that are flexible, lightweight and able to absorb shock. These characteristics are important to ensure optimal protection without affecting the body's anatomical movements during physical activity. Therefore, the design of protectors needs to consider the user's comfort as well as effectiveness in preventing injuries [7]. The lack of research on foot protectors for traditional sports such as Sepak Raga Tuju creates an important gap in efforts to improve player safety. Further research on the design and performance of this protective equipment can not only improve product quality, but also help assess the actual level of risk faced by athletes. Improved innovations in protective equipment also have the potential to improve the quality of the game and encourage the participation of more players without neglecting safety aspects.

2.2 Sports Product Design Innovation

Sports product design has evolved in line with technological advances and an increased understanding of consumer needs. Innovation in design is now not only focused on aesthetic aspects, but also on functional, ergonomic and safety factors that directly affect athlete performance and user experience [8]. The use of high-tech materials such as carbon fiber and composite materials has enabled the production of lighter and stronger equipment, something that is very important in high-performance sports such as cycling and snowboarding [9].In addition to materials, the use of performance monitoring technology through smart sensors has also changed the design process of sports equipment. This technology allows real-time data to be collected, providing a competitive advantage in analyzing performance and identifying weaknesses more accurately [10]. Ergonomic factors are also increasingly prioritized in ensuring that product design is in line with human anatomy to reduce the risk of injury. For example, high-performance running shoes are now designed with arch support and shock absorption systems that can reduce pressure on the knee and ankle joints. In addition, sustainability aspects are increasingly becoming a concern in the sports industry. There is an increase in the use of green materials and sustainable production processes that emphasize recycled content and a low carbon footprint [11]. This trend demonstrates the industry's sensitivity to the sustainable development agenda and changing consumer preferences. Overall, sports product design innovation is moving towards producing safer, more effective and environmentally and socially responsible products.

2.3 Sustainable Development Goals (SDG 9 & SDG 12)

2.3.1 SDG 9: Industry, Innovation and Infrastructure – Innovation and Local Product Development

SDG 9 emphasizes sustainable and inclusive industrial development with a focus on innovation and building strong and resilient infrastructure. Innovation plays a key role in generating new solutions that increase efficiency, productivity and reduce negative environmental impacts [12]. In the local context, innovation efforts that use waste as the base material for product such as foot protection for traditional sports support the local technology development agenda and expand the role of institutions such as polytechnics and community colleges in providing community-based solutions [13].Using waste as the main source of manufacturing products can improve resource efficiency, reduce production costs and meet the needs of a market that increasingly emphasizes quality at an affordable price [14]. In addition, innovation in the production process also contributes to the development of small and medium-sized enterprises (SMEs) through the production of environmentally friendly and innovative foot protection products for traditional sports, demonstrating the application of local technology in a competitive market [15]. The activities provide scope for students to hone hands-on skills while gaining entrepreneurial and innovation experience. The design of products from recycled materials has huge potential to increase resource efficiency and save costs and in a way that satisfies a market that is ever more focused on quality at a reasonable price. Through the use of materials that previously were regarded as waste, pressure on the environment can be reduced and new scope created for the manufacture of more sustainable products [16]. This method produces economic benefits via cost reduction in production as well as the ease of the cautious and cautious handling of resources. Moreover, according to [17] innovation is not a phrase given only to the production of final products but also to producing better more efficient means of production and distribution. By meeting the needs of consumers who are sensitive to price and quality, products from recycled materials have the potential to become a leading choice in a competitive market. This approach indirectly contributes to the development of small and medium-sized enterprises (SMEs) by producing environmentally friendly, innovative products and foot protection with waste materials demonstrating the application of competitive local technology in developing traditional sports markets.

2.3.2 SDG 12: Responsible Consumption and Production – Waste Reuse

SDG 12 emphasizes sustainable consumption and production patterns through circular economy approaches such as waste reduction, reuse and responsible recycling [16]. In the context of producing footwear from waste, this approach not only reduces the amount of waste going to landfills, but also converts waste materials such as polyethylene foam and used PVC pipes into useful and economically valuable products [17].Lightweight, impact-resistant and low-cost recycled products have been identified as suitable options for the manufacture of sports footwear, especially for students and young people [18]. The use of recycled materials also reduces the dependence on new materials, thus lowering the carbon footprint throughout the product's life cycle [19]. This approach is in line with the principles of SDG 12 which emphasizes responsible consumption and production and the reduction of negative impacts on the environment [20].In the context of education, the application of this sustainable design concept not only increases environmental awareness among TVET students but also strengthens their technical skills in producing environmentally friendly products. Community projects based on recycled material innovation have proven effective in supporting the implementation of SDG 12 through pollution reduction and the formation of a culture of responsible production in society [21]. The design for sustainability strategy also helps bring about SDG 12 realization because it takes into consideration factors of sustainability at the product development level. This rule demands designs that are viable enough to extend their lifespan, be repaired and have parts recycled when they get disposed of [22]. In the educational environment, the application of this concept not only elevates the environmental awareness of TVET students but also enhances their technical skills in producing environmentally friendly products. In addition, [23] emphasized that community projects based on recycling material innovation are directly instrumental in fulfilling SDG 12. By following such an approach, not only can pollution be reduced, but a sense of responsible production can also be fostered in society. Thus, the development of foot protection from waste products is not only meeting the protective needs in traditional sports but also meeting the global agenda of sustainability by saving resources and disposing of no waste.

3. RESEARCH METHODOLOGY

Quantitative research design was employed in this study as a series of laboratory tests to evaluate physical and chemical foot protector properties made from recycled materials, which in this instance were polyethylene foam-based insulation pipes and other supplementary materials. The tests were conducted at the Biodegradable Plastics Testing Laboratory, Advanced Materials Research Centre (AMREC), SIRIM Berhad, as per accepted international standards. There were three major methods utilized in this testing process, i.e., Water Absorption Test, Tensile Strength Test and Fourier Transform Infrared Spectroscopy (FTIR) Analysis.

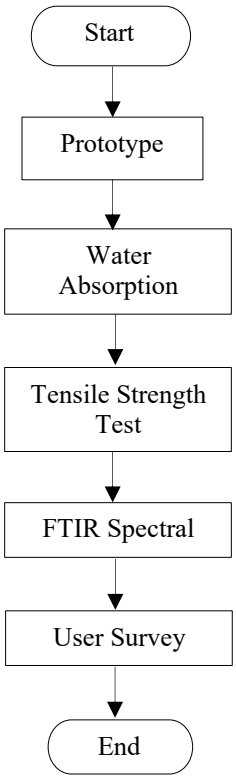

Figure 1: Research Methodology Flowchart

i. Water Absorption Test

This test was carried out by the ASTM D570-22 standard (Standard Test Method for Water Absorption of Plastics). Equipment used included an electronic balance with four decimals (Mettler Toledo MS204TS) and a Memmert GmbH drying oven. The specimens of the foot protector were first dried in an oven for four hours and weighed to obtain the initial dry weight. The samples were then submerged in water maintained at a constant temperature of 23–25°C for 24 hours, removed, wiped on their surface and reweighed to obtain the wet weight. The percentage water absorption was calculated using the formula provided. A total of three specimens were tested in this case, where the outcome indicated that there was an average water absorption of 70.2%. This implies a high absorption rate, thus having implications on the material being suitable for use when applied under conditions that are exposed to water.

ii. Tensile Strength Test

Tensile strength tests were carried out according to the ASTM D638-22 standard (Standard Test Method for Tensile Properties of Plastics) using a Universal Testing Machine (Tinius Olsen H10K) equipped with a 10,000 N load cell. Specimens were cut in dumbbell shape according to the standard conditions (length = 165 mm, width = 10 mm, thickness = 10 mm). The experiment was performed at the rate of 50 mm/min with grip separation of 100 mm and span length of 50 mm. Parameters that were recorded include Ultimate Tensile Strength (UTS), Ultimate Strain and Modulus of Elasticity. For the three samples tested, mean UTS was 0.22 MPa, ultimate strain was 82.75% and modulus of elasticity was 0.34 MPa. These results revealed that the material had good elasticity but a moderate tensile strength, as was expected for foams based on polyethylene.

iii. FTIR Spectral Analysis

FTIR analysis was performed by ASTM E1252-98 (2021) (Standard Practice for General Techniques for Obtaining Infrared Spectra for Qualitative Analysis) with a Thermo Scientific Nicolet Summit X FTIR spectrometer in the Attenuated Total Reflectance (ATR) mode. The spectra were recorded within the wavenumber range of 4,000–600 cm^{-1} at room temperature. The analysis revealed significant peaks at ~3386 and 3203 cm^{-1} (N–H/O–H stretching), 2916–2848 cm^{-1} (C–H stretching) and 1730–1680 cm^{-1} (C=O stretching), with some other related peaks due to C–O stretching and C–H bending. Library database comparison gave the most similarity with Black Rubber filled polymer (78.50%) and Polyethylene (72.99%), thereby confirming the material's main composition.

iv. Study Design

The tests were performed under a controlled lab environment at room temperature of 24±3°C and relative humidity of 53–85%. No limitations of compliance were set because the main intention was to determine the material properties for the creation of green innovation products. The data gathered were analyzed descriptively to assess the potential of the material in terms of safety, comfort and sustainability of use in the indigenous sport Sepak Raga Tuju.

4. RESULTS AND DISCUSSION

The study was conducted to evaluate the physical and chemical properties of foot protectors made of recycled materials for use in the traditional sport of Sepak Raga Tuju. The evaluation was conducted using three major testing procedures, that is, Water Absorption Test (ASTM D570-22), Tensile Strength Test (ASTM D638-22) and Fourier Transform Infrared Spectroscopy (FTIR) Analysis (ASTM E1252-98).

i. Water Absorption Test (ASTM D570-22)

The test results showed an average water absorption rate of 70.2% after the samples were dried in an oven for four hours, followed by a 24-hour soaking process at a controlled temperature of 23–25 °C. This value indicates that the dense black sponge material used has significant hydrophilic properties, with a high water and moisture absorption capacity. This property can provide comfort to the user through sweat absorption and reduction of moisture on the skin surface. However, the high-water absorption rate was identified as a major drawback of this material, as it can affect the long-term mechanical performance, increase the weight of the foot protector when use in wet conditions and promote the growth of microorganisms. This issue becomes more significant when the protector is repeatedly used in humid or wet environments. To address this drawback, the application of a waterproof coating or the integration of a hydrophobic outer layer is proposed. This approach has the potential to increase water resistance without compromising internal comfort, while also improving the hygiene and structural durability of the foot protector in the long term.

ii. Tensile Strength Test (ASTM D638-22)

Based on the test results, the Ultimate Tensile Strength (UTS) value obtained was 0.22 MPa, with a maximum elongation of 82.75% and a modulus of elasticity of 0.34 MPa. This value indicates that the material has moderate mechanical strength and high elasticity, typical characteristics of polyethylene foam or rubber polymer-based materials.

The high elasticity proves the material's ability to absorb impact energy and provide physical protection, making it suitable for foot protection functions. However, the low tensile strength value indicates that the resistance to repeated traction is limited and this may affect the durability of the structure when used for long periods of time or in intensive activities. Therefore, the use of additional reinforcing materials or design improvements may be necessary to improve the mechanical performance of the protector.

iii. FTIR Analysis (ASTM E1252-98)

FTIR spectrum showed several major peaks like ~3386 and 3203 cm^{-1} (N–H or O–H stretch), 2916 and 2848 cm^{-1} (C–H stretch) and 1730–1680 cm^{-1} (C=O stretch). Spectra were matched with the library database, where Black Rubber filled polymer (78.50%) and Polyethylene (72.99%) had the highest match. This outcome confirmed that the main materials utilized were synthetic polymers from rubber and polyethylene, which are strongly recognized to be

light in weight, shock resistant and worth a lot less to manufacture. The presence of C=O and O–H peaks is also likely caused by additives or fillers that help to strengthen mechanical properties and water absorption capabilities.

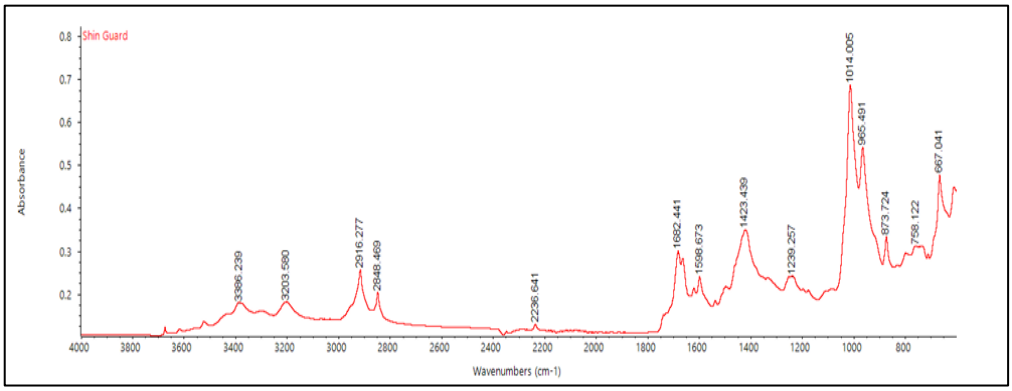

Figure 2: FTIR Spectrum of Shin Guard

Table 1: Comparison of Prototype vs Commercial Shin Guards

Property	Prototype	Commercial
Tensile Strength (MPa)	0.22	15–25
Elongation (%)	82.75	50–150
Water Absorption (%)	70.2	<5
Cost (RM/unit)	Very Low	High
Sustainability	High (Recycled)	Low (Synthetic)

iv. Implications for Foot Protector Design

Overall, the three tests showed that the foot protectors are very elastic, have good shock absorption capacity and are able to absorb a large amount of moisture. These characteristics are very suitable for application in the sport of Sepak Raga Tuju, a game that not only requires effective protection but also demands high physical intensity. In this sport, players must move agilely and quickly, making smoothness of movement a very important aspect. Therefore, the intended characteristics must be able to provide adequate protection without hindering the player's freedom to perform various movements [24]. This includes the ability to jump, dodge and adjust positions quickly, while still maintaining safety from any risk of injury. Thus, the application of these characteristics not only improves player performance but also guarantees a safer and more enjoyable playing experience. It is important to create awareness among players and coaches about the use of proper protective equipment to prevent injuries in traditional games such as Sepak Raga Tuju [25]. In addition, educating players on the importance of proper protective gear can significantly reduce the incidence of injuries and enhance their overall performance in traditional sports.

6. CONCLUSION

This study proves that the production of foot protection using recycled materials is a viable approach in the development of sustainable, affordable and environmentally friendly traditional sports equipment. The evaluation of the physical and chemical properties of the materials was carried out through three main methods, namely Water Absorption Test (ASTM D570-22), Tensile Strength Test (ASTM D638-22) and FTIR Analysis (ASTM E1252-

98).The test results showed that the test material absorbed water at a high rate (70.2%), had moderate tensile strength (0.22 MPa) and high elasticity (maximum elongation 82.75%). FTIR analysis confirmed that the main materials consisted of polyethylene and filled rubber, which functionally could provide impact protection and flexibility of movement to the players. However, high water absorption was identified as a major limitation that could affect long-term durability when used in humid environments. Therefore, improvements such as the addition of a waterproof layer or the integration of an external protective material are proposed to improve the water resistance and structural durability of the product. The contribution of this study is significant as it demonstrates how waste can be converted into value-added products, thus supporting the achievement of Sustainable Development Goals (SDGs) 9 and 12. From the perspective of SDG 9, this innovation demonstrates the capability of local technology to produce sports products that meet international standards and are suitable for use in schools, TVET institutions and communities. In terms of SDG 12, the reuse of waste materials in product development demonstrates responsible production and consumption practices, reduces solid waste and expands the economic value of recycled materials. In addition, further studies are recommended to strengthen this innovation in terms of technical and practical aspects, in line with the actual needs of use in the context of traditional sports. Among the aspects that need attention include the development of new environmentally friendly composites that have better water resistance and higher mechanical properties, to ensure optimal protection and long-term durability. In addition, field ergonomic tests should be conducted to assess the level of comfort, performance and suitability of using the foot protector in real game situations, thus ensuring that the product meets the needs of users in terms of function and comfort. Furthermore, studies on long-term durability, especially against wear, moisture and repeated use pressure, are also important to assess the level of usability and efficiency of the product when used continuously in sports activities. Overall, this study not only reduces environmental impact through a recycling approach, but also empowers local industries towards sustainable development and increases sustainability awareness among students and the community.

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