Evaluation of Existing Horseshoes and Design Alternatives for Horses Employed in Horse-Drawn Carriages (Tartanilla) for Cebu City, Philippines

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Evaluation of Existing Horseshoes and Design Alternatives for Horses Employed in Horse-Drawn Carriages (Tartanilla) for Cebu City, Philippines

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Abstract: *The design of hoofwear for horse-drawn carriages requires a careful balance of performance, comfort, cost, and sustainability. This study aims to evaluate and select optimal materials for the outer metallic shoe and inner non-metallic hoof pad using a multi-criteria decision-making approach. The Analytical Hierarchy Process (AHP) was used to assign weights to criteria such as durability, environmental impact, and cost, while the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) ranked material alternatives. Results showed that Aluminum Alloy (6061-T6) is the best choice for the outer shoe due to its strength, corrosion resistance, and affordability. For the hoof pad, Polylactic Acid (PLA) emerged as the top material, offering biodegradability and sufficient mechanical strength. This study confirms the effectiveness of AHP-TOPSIS in material selection and supports the development of sustainable hoofwear solutions for urban horse-drawn carriage operations.*

Keywords: Hoofwear; Material selection; AHP; TOPSIS; sustainability

1. INTRODUCTION

These instructions give you the guidelines for preparing papers for (IEICES). All manuscripts must be in English and should be at least 6 but no more than 8 pages of text using this word template. The paper should be written in A4 size. Your manuscript is in two columns format with Times New Roman 10. The width of each column should be 8.0 cm with 1 cm spacing between the two columns. The use of horse-drawn carriages, locally known as "Tartanilla," is an enduring part of Cebu City's cultural and historical identity. These carriages are not only a mode of transport but also a significant attraction for both locals and tourists, offering a meaningful journey through the city's streets. However, as urbanization and tourism intensify, the welfare of the horses employed in this industry comes under scrutiny. Central to this concern is the health of the horses' hooves, which are crucial to their overall well-being and performance.

Horses used in urban settings, especially those subjected to continuous hard surface work, are prone to hoof-related issues. According to [1], hoof health is paramount in maintaining a horse's functionality and preventing lameness—a condition that not only diminishes the animal's quality of life but also directly affects its ability to perform in demanding urban environments. Lameness, often caused by poor hoof conditions, is one of the most common and serious health problems in working horses, leading to a significant reduction in their operational lifespan.

Urban environments in Cebu City, Philippines pose unique challenges to hoof health, including hard pavement surfaces, irregular terrain, and increased exposure to contaminants. The welfare and performance of horses employed in horse-drawn carriages, especially in urban environments, are significantly influenced by the condition of their hooves and the footwear they are provided. These factors can exacerbate the wear and tear on hooves, leading to a higher incidence of conditions such as laminitis, thrush, and sole bruises [2]. The traditional horseshoe, while effective in many respects, often fails to address the specific needs of working horses in urban settings. Continuous exposure to hard surfaces, combined with the demands of pulling carriages, leads to hoof-related issues that compromise the health of the horses and the safety of the operations. Moreover, the improper or inadequate hoof care practices commonly observed in the tourism industry in Cebu City, Philippines further compound these issues, making it essential to explore innovative solutions that enhance hoof protection and management.

Furthermore, the ethical considerations surrounding the use of animals in tourism have gained prominence in recent years, emphasizes the need for sustainable tourism practices that prioritize animal welfare, aligning with broader global efforts to ensure responsible consumption and production. This growing awareness spurs a call to action among stakeholders, including local governments, animal welfare organizations, and tourism operators, to adopt practices that not only protect animals but also sustain the long-term viability of tourism industries.

In response to these challenges, the current research integrates a scientific assessment of hoof health with the development of a modular hoof wear system, designed to mitigate the adverse effects of urban environments on horses. This hoof wear system, which incorporates advanced materials and ergonomic design, aims to provide superior protection and support, thereby enhancing the horses' overall health and performance. The development of a modular hoofwear system for these horses necessitates a careful consideration of materials that optimize both the outer shoe and the inner hoof pad. The outer shoe must be lightweight to reduce the burden on the horse while ensuring durability to withstand the rigors of urban terrains. On the other hand, the inner hoof pad, which serves as a cushioning layer, must be selected based on its ability to minimize environmental impact, thus aligning with the growing emphasis on sustainable and responsible materials in equine management.

This research addresses a critical gap in the management of hoof health in urban environments, offering both a practical solution in the form of a patentable modular hoofwear system and a comprehensive assessment of current practices. The findings are expected to contribute to the broader discourse on animal welfare in tourism, providing valuable insights that could influence policy and operational standards in Cebu City. The project underscores the importance of integrating technology, ethics, and sustainability in managing the intersection of animal welfare and urban tourism.

To achieve these objectives, a systematic approach involving material selection is essential. For the outer shoe, various metals will be analyzed using the Analytical Hierarchy Process (AHP) combined with the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). This analysis will prioritize materials that offer the best combination of lightweight properties and durability. Simultaneously, the inner hoof pad will be evaluated using AHP-TOPSIS, focusing on non-metallic materials, with environmental impact as the primary criterion.

Following the material selection process, the chosen materials will be subjected to further design analysis. Using 3D CAD modeling, the selected materials will be designed to meet specific functional requirements and dimensions. Additionally, finite element analysis (FEA) will be conducted to assess the performance of the materials under simulated working conditions, ensuring that the final design is not only effective but also safe and sustainable [3].

This research aims to advance the development of a hoofwear system that significantly improves the well-being of horses while promoting sustainable practices in urban carriage tourism. Through a rigorous analysis of material options and comprehensive design evaluations, this study will contribute to the creation of a more humane and efficient solution for horse-drawn carriages. The significance of this research extends beyond the immediate welfare of the horses. It aligns with several Sustainable Development Goals (SDGs), including Good Health and Well-being (SDG 3), Decent Work and Economic Growth (SDG 8), and Partnerships for the Goals (SDG 17). By improving hoof health, the study promotes not only the well-being of horses but also supports sustainable livelihoods for carriage operators. Furthermore, the collaborative nature of the project—bringing together researchers, government agencies, and industry stakeholders—exemplifies the kind of partnership essential for achieving sustainable development outcomes.

2. REVIEW OF RELATED LITERATURE

The design and material selection for equine hoof pads played a crucial role in ensuring the well-being of horses and the efficiency of horse-drawn carriages. Hoof pads were essential components in providing comfort, protection, and performance. Material selection was influenced by multiple factors, including durability, environmental impact, cost, and comfort. Various materials, both metallic and non-metallic, had been explored to determine their suitability for hoof pad applications.

For the outer metallic part, aluminum alloys, such as 6061-T6, were widely used in engineering applications due to their favorable combination of strength, weight, and corrosion resistance. In the context of hoof pads, non-metallic materials provided a lightweight yet durable option, which could have improved the overall efficiency of horse-drawn carriages. However, concerns regarding their abrasion resistance and cost had to be considered. Stainless steel, particularly grade 316, was known for its high corrosion resistance and durability [4]. It had been used in various high-stress applications, including equestrian equipment. The metal's excellent tensile and impact strength made it a viable candidate for the outer metallic part, though its weight and cost could have been limiting factors. Titanium alloys, such as Ti6Al-4V, were renowned for their exceptional strength-to-weight ratio and resistance to wear and corrosion. They were highly durable, making them suitable for demanding applications. However, the high cost and limited availability could have been drawbacks. Magnesium alloys, like AZ31B, offered a low-density alternative with good mechanical properties. Their light weight could have reduced the overall load on horses, potentially improving performance. Yet, their lower abrasion resistance and cost had to be carefully evaluated.

For the inner non-metallic hoof pad, PLA was a biodegradable polymer derived from renewable resources, making it an environmentally friendly option [5]. It had been studied for various applications due to its favorable mechanical properties and biodegradability. In the context of hoof pads, PLA's ability to decompose naturally aligned with sustainability goals, though its performance in terms of impact strength and durability might have needed enhancement. TPU was known for its flexibility, eco-friendliness, recyclability, and biocompatibility. It had also been used in a range of applications requiring high wear resistance and comfort. TPU's performance in hoof pads could have provided a balance between comfort and durability, though its biodegradability was relatively low. Kevlar composites were renowned for their high strength and durability. They were often used in high-performance applications, including protective gear. For hoof pads, Kevlar composites offered excellent impact resistance, but their environmental impact and cost were significant considerations. PEEK was a high-performance polymer with exceptional mechanical and thermal properties. It was known for its high durability and chemical resistance. Despite its advantages, PEEK's cost and biodegradability limited its suitability for environmentally focused applications, which could have been challenging compared to its counterparts. Rubber compounds were widely used in various applications due to their elasticity, impact resistance, and comfort. In hoof pads, rubber could have provided effective shock absorption and comfort, though its environmental impact and longevity should have been evaluated.

Both AHP and TOPSIS were effective methodologies for multi-criteria decision-making in material selection [6,7]. AHP helped prioritize criteria based on their importance, while TOPSIS evaluated alternatives by their distance from the ideal solution. These methods enabled a comprehensive assessment of material options by

considering various factors, including mechanical properties, cost, and environmental impact.
The importance of environmental impact in material selection was well-documented, with an increasing emphasis on sustainability and life-cycle analysis. Biodegradability, recyclability, and reduced environmental footprint were crucial aspects in selecting materials for sustainable applications.

3. METHODOLOGY

To effectively assess the suitability of various materials for the hoofwear system, adopting a systematic approach that integrated multiple analytical techniques was important. The methodology was divided into two primary phases: material selection and design analysis.
In the material selection phase, the first step involved defining and standardizing the evaluation criteria for both metallic and non-metallic materials. These criteria included tensile strength, flexural strength, impact strength, hardness, weight, cost, and environmental impact (biodegradability). The next step was a comprehensive review of literature and material databases, which was conducted to gather data on these criteria for a wide range of materials. This included metals such as aluminum, stainless steel, and various alloys, as well as non-metallic materials like thermoplastic polyurethane (TPU), polylactic acid (PLA), and others.
Lastly, for this first phase, the Analytical Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) were used to evaluate and rank these materials based on their performance against the identified criteria. AHP helped in determining the relative importance of each criterion, while TOPSIS facilitated the selection of the most suitable materials by comparing their performance against ideal and negative-ideal solutions.
In the design phase, the first step started with material selection based on the results from the AHP-TOPSIS analysis. The most promising materials for both the outer shoe (metallic) and the inner hoof pad (non-metallic) were selected. For the outer shoe, factors such as lightweight and durability were prioritized, while for the inner hoof pad, environmental impact and other criteria were emphasized.
Next, the selected materials were used to create detailed 3D CAD models of the hoofwear system. This included the modular design components, ensuring that the designs accommodated features such as adjustable angles for customized fit and locking mechanisms for secure assembly.
Then, the CAD models underwent finite element analysis to simulate the performance of the hoofwear system under various conditions. This analysis assessed factors such as stress distribution, deformation, and overall durability to ensure the design met functional requirements as shown in Fig. 1. The methodology aimed to select the optimal materials for both the outer shoe and inner hoof pad, ensuring the development of a high-quality, functional, and sustainable hoofwear system for horses employed in horse-drawn carriages.

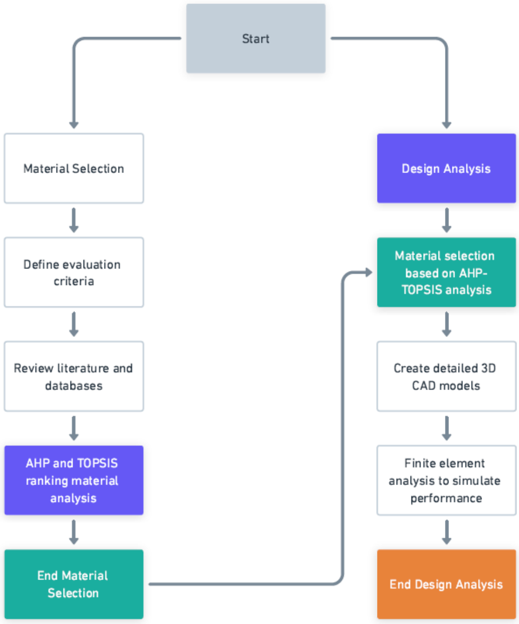


Fig. 1. Design Analysis Flowchart.

4. RESULTS AND DISCUSSION

The AHP methodology involved constructing and normalizing pairwise comparison matrices for both criteria and sub-criteria. By calculating the normalized weights and aggregating them, a comprehensive set of weights for evaluating the metallic part was derived. This systematic approach ensured that each criterion's significance was appropriately reflected in the final assessment, allowing for a well-rounded evaluation based on both technical and economic factors.
In this research, the Analytical Hierarchy Process (AHP) was applied to evaluate the outer metallic part by first establishing a clear goal: to assess the component based on multiple criteria. The criteria were categorized into three main areas: reliability and comfortability, economic viability, and durability. Within reliability and comfortability, the sub-criteria included weight, impact strength, and abrasion resistance, with weight being the most critical factor. Economic viability focused on price, and durability encompassed tensile strength, flexural strength, and hardness, with hardness being the least important.
To determine the relative importance of these criteria, pairwise comparison matrices were used. The matrix for criteria comparison revealed that reliability and comfortability were significantly more important than economic viability, which, in turn, was more important than durability. This prioritization was reflected in the assigned weights, where reliability and comfortability received a weight of 7, economic viability 3, and durability 21.
Within each criterion, further sub-criteria were evaluated. For example, under reliability and comfortability, weight was assigned the highest priority, followed by impact strength and abrasion resistance. In the durability category, tensile strength was considered more critical than flexural strength, which was in turn more important than hardness.
The AHP methodology involved constructing and normalizing pairwise comparison matrices for both criteria and sub-criteria. These matrices were used to

	Reliability and Comfortability			Economic viablity	Durability		
	Weight	*Impact Strength*	*Abrasion Resistance*	*Price*	*Tensile Strength*	*Flexural Strength*	*Hardness*
Weight	1	3	3	3	5	7	9
Impact Strength	0.333333333	1	1	3	3	5	7
Abrasion Resistance	0.333333333	1	1	1	3	3	5
Price	0.333333333	0.333333333	1	1	1	3	3
Tensile Strength	0.2	0.333333333	0.333333333	1	1	1	3
Flexural Strength	0.142857143	0.2	0.333333333	0.333333333	1	1	1
Hardness	0.111111111	0.142857143	0.2	0.333333333	0.333333333	1	1
Total	2.453968254	6.00952381	6.866666667	9.666666667	14.33333333	21	29

Fig. 2. AHP-Pairwise Comparison Matrix for the outer metallic part.

calculate the normalized weights, which reflected the relative importance of each criterion and sub-criterion. Aggregating these weights provided a comprehensive assessment framework that aligned with the project's goals as shown in Fig. 2.

Following the AHP, TOPSIS was employed to rank the materials based on their performance against the defined criteria. This method involved comparing each material to ideal and negative-ideal solutions, allowing for a comparative analysis that highlighted the most suitable materials. The materials were evaluated on their performance in terms of the weighted criteria, including tensile strength, impact strength, cost, weight, and environmental impact.

The same was also done for the non-metallic hoof pad. The selection of materials for the inner non-metallic hoof pad involved a comprehensive evaluation using the Analytical Hierarchy Process (AHP), focusing on several key criteria to ensure optimal performance and sustainability. This methodology applied a structured approach to assess materials based on environmental impact, comfortability, economic viability, and durability, with a specific emphasis on biodegradability due to its critical importance. The implementation ensured that the non-metallic hoof pad materials were selected based on a balanced consideration of environmental impact, comfort, economic viability, and durability, leading to a well-rounded and effective hoofwear solution.

To begin with, the criteria for evaluating non-metallic materials were categorized into four main areas: environmental impact, comfortability, economic viability, and durability. Each category was defined by specific sub-criteria. Environmental impact was assessed primarily by biodegradability in a natural environment, which was deemed the most critical criterion. The comfortability criteria included sub-criteria such as weight and impact strength, reflecting the need for a lightweight and resilient hoof pad. The economic viability criterion was evaluated based on the price sub-criterion, addressing the cost-effectiveness of the materials. The durability criteria encompassed tensile strength, flexural strength, and hardness sub-criteria, with hardness being the least significant criterion. The relative importance of these criteria was determined through pairwise comparison matrices. The matrix revealed that environmental impact, particularly biodegradability, held the highest priority among the criteria. Comfortability followed, with weight and impact strength being crucial for user comfort. Economic viability was considered next, emphasizing the importance of cost, while durability, despite its significance, was least prioritized, with hardness being the least important factor.

Using AHP, pairwise comparison matrices were constructed to quantify the relative importance of each criterion and sub-criterion. These matrices allowed for the normalization of weights, reflecting the relative significance of each criterion as shown in Fig. 3. For example, environmental impact was assigned the highest weight due to its paramount importance, followed by comfortability, economic viability, and durability, in descending order of importance. Within the comfortability criterion, weight and impact strength were evaluated, with weight being prioritized. In the durability category, tensile strength and flexural strength criteria were considered more critical than hardness. This prioritization ensured that the most influential factors were accurately represented in the material selection process. Following the determination of weights through AHP, each non-metallic material was assessed based on these criteria. The evaluation involved comparing materials against the weighted criteria, allowing for a systematic ranking of options. The materials were judged on their biodegradability, weight, impact strength, price, tensile strength, flexural strength, and hardness.

After the AHP evaluation, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was employed to rank the materials. TOPSIS compared each material to ideal and negative-ideal solutions, providing a comparative analysis based on the weighted criteria. This method highlighted the materials that best met the project's requirements for performance and sustainability.

	Environment Impact	Comfortability		Economic viability	Durability		
	Biodegrability (natural)	*Weight*	*Impact Strength*	*Price*	*Tensile Strength*	*Flexural Strength*	*Hardness*
Biodegrability (natural)	1	3	3	3	5	7	9
Weight	0.333333333	1	1	3	3	5	7
Impact Strength	0.333333333	1	1	1	3	3	5
Price	0.333333333	0.333333333	1	1	1	3	3
Tensile Strength	0.2	0.333333333	0.333333333	1	1	1	3
Flexural Strength	0.142857143	0.2	0.333333333	0.333333333	1	1	1
Hardness	0.111111111	0.142857143	0.2	0.333333333	0.333333333	1	1
Total	2.453968254	6.00952381	6.866666667	9.666666667	14.33333333	21	29

Fig. 3. AHP-Pairwise Comparison Matrix for the Inner hoof pad part.

Weightage	0.37806632	0.206712817	0.153698507	0.108064875	0.072827841	0.046627279	0.03400236					
	Weight	Impact Strength	Abrasion Resistance	Price	Tensile Strength	Flexural Strength	Hardness	S+	Si-	Pi	**Rank**	
Aluminum Alloys (6061-T6)	0.04382916	0.087709447	0.059549073	0.008011321	0.011219054	0.006839076	0.005218129	0.06043186	0.15325648	0.717196267	**1**	Aluminum Alloys (6061-T6)
Zinc Alloy (Zamak 3)	0.108761249	0.027907551	0.066554846	0.00534088	0.01276651	0.008824614	0.004504069	0.1271981	0.100179805	0.440587246	**6**	Zinc Alloy (Zamak 3)
Brass (C36000)	0.137980689	0.022326041	0.04203464	0.008901467	0.013927101	0.009707076	0.005492767	0.144591501	0.094069286	0.394154762	**10**	Brass (C36000)
Copper Alloy (C11000)	0.144473898	0.015947172	0.070057733	0.008011321	0.008124143	0.007500922	0.004558997	0.160925267	0.089938592	0.358515542	**11**	Copper Alloy (C11000)
Stainless Steel (316)	0.129864178	0.019933965	0.03152598	0.00534088	0.022438108	0.016766767	0.010436258	0.136170056	0.103292649	0.431351719	**7**	Stainless Steel (316)
Stainless Steel (304)	0.129864178	0.107643412	0.035028867	0.006231027	0.019536628	0.011471999	0.011040463	0.105819269	0.135943685	0.562301555	**3**	Stainless Steel (304)
Titanium (Grade 5, Ti6Al-4V)	0.071912288	0.087709447	0.028023093	0.09791614	0.036752073	0.019855382	0.019169758	0.108228974	0.116018424	0.517367981	**5**	Titanium (Grade 5, Ti6Al-4V)
Bronze (Aluminum Bronze)	0.124994271	0.03986793	0.045537526	0.019583228	0.023211836	0.011471999	0.008239151	0.124344895	0.089317282	0.418030383	**8**	Bronze (Aluminum Bronze)
Magnesium Alloy (AZ31B)	0.02889478	0.035881137	0.02101732	0.011571907	0.010638758	0.005294769	0.003460443	0.083142786	0.153696153	0.648947988	**2**	Magnesium Alloy (AZ31B)
Nickel Alloy (Inconel 718)	0.132948452	0.031894344	0.02627165	0.035605869	0.040040417	0.028679996	0.018126133	0.133297646	0.089261072	0.401067515	**9**	Nickel Alloy (Inconel 718)
Mild steel (A36)	0.127429224	0.099669826	0.0525433	0.00133522	0.016248285	0.010479229	0.007140598	0.10866709	0.130541399	0.545722268	**4**	Mild steel (A36)

Fig. 4. Results for the outer metallic part.

The selected materials, based on the AHP-TOPSIS analysis, were then further analyzed using 3D CAD software. This included detailed design evaluations to ensure the materials met all functional and performance requirements. Finite Element Analysis (FEA) was also conducted to optimize the design for durability and effectiveness. The Analytical Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) were applied to evaluate various metals for the outer metallic part of the hoofwear. This comprehensive analysis considered multiple criteria, including impact strength, abrasion resistance, price, tensile strength, flexural strength, and hardness, each weighted according to its importance.

In the evaluation of the criteria weighting, as shown in Fig. 4, the criteria were prioritized as follows: weight was 0.37806632, impact strength was 0.206712817, abrasion resistance was 0.153698507, price was 0.108064875, tensile strength was 0.072827841, flexural strength was 0.046627279, and hardness was 0.03400236. Weight was the most critical factor, emphasizing the need for materials that were as lightweight as possible for the good of horse health in terms of its mobility. Impact strength was the next critical factor, ensuring the material could withstand significant forces without failure. Abrasion resistance followed, highlighting the importance of resistance to wear and tear. Price was also a significant consideration, ensuring cost-effectiveness. Tensile strength and flexural strength were crucial for durability, while hardness, although still important, had the least weight in the decision-making process.

For the material selection, the results of the AHP-TOPSIS analysis were summarized, reflecting how each material performed across the weighted criteria. Aluminum Alloys (6061-T6) ranked the highest with a score of 0.717196267. Aluminum Alloys (6061-T6) performed excellently across all areas, making it a highly favorable option. It was also relatively cost-effective, contributing to its high ranking. Its balance of performance and cost made it a strong contender. Magnesium Alloy (AZ31B), with a score of 0.648947988, ranked second highest among the evaluated materials. It scored well in some areas, and despite its higher price, its overall performance in critical criteria made it the second choice. Its lightweight further enhanced its appeal for applications where reducing mass was essential.

Stainless steel (304) ranked third with a score of 0.562301555. It excelled in impact strength and had a reasonable performance in abrasion resistance. Its higher cost and moderate performance in other criteria slightly affected its overall ranking but still positioned it as a viable choice. Mild steel (A36) scored 0.545722268 and ranked fourth, showing solid performance in impact strength and a good balance of other properties. Its affordability and decent performance in key areas placed it in the mid-range but lower than higher-performing materials like aluminum alloys and magnesium alloys.

Titanium (Grade 5, Ti6Al-4V) had a score of 0.517367981. Titanium (Grade 5) performed well, particularly in impact strength and abrasion resistance. However, its higher cost and lower scores in some other criteria slightly reduced its overall ranking compared to materials like aluminum alloys and magnesium alloys. Stainless steel (316) ranked sixth with a score of 0.431351719 and was strong in impact strength but fell behind in price. Its higher cost and moderate performance in other areas limited its overall ranking.

Nickel alloy (Inconel 718), with a score of 0.401067515, was evaluated based on its impact strength and abrasion resistance. However, its higher cost and lower scores in other criteria resulted in a lower ranking. Bronze (Aluminum Bronze) had a score of 0.418030383 and performed reasonably well but did not excel in any particular area. Its performance was adequate but not outstanding compared to top-ranking materials. Brass (C36000) ranked lower with a score of 0.394154762. It showed moderate performance across the criteria but fell short in impact strength and abrasion resistance, which affected its overall ranking.

Copper Alloy (C11000) scored 0.358515542, showing adequate performance but not standing out in any specific area. Its lower score in impact strength and abrasion resistance placed it towards the lower end of the ranking. Zinc alloy (Zamak 3) had a score of 0.440587246 and ranked lower primarily due to its poorer performance in impact strength and abrasion resistance. Its relatively high price further affected its overall ranking.

The AHP-TOPSIS analysis for selecting the most suitable material for the inner non-metallic hoof pad of

Weightage	0.37806632	0.206712817	0.153698507	0.108064875	0.072827841	0.046627279	0.03400236					
	Biodegrability (natural)	Weight	Impact Strength	Price	Tensile Strength	Flexural Strength	Hardness	S+	Si-	Pi	**Rank**	
Nylon (Polyamide)	0.066061491	0.057265076	0.009293108	0.002668141	0.007987698	0.008047762	0.011643703	0.138331901	0.150697988	0.521392402	**6**	Nylon (Polyamide)
Thermoplastic Polyurethane (TPU)	0.090083851	0.059754862	0.061954055	0.002001106	0.006276048	0.006627569	0.009056214	0.125241037	0.145063309	0.53666658	**5**	Thermoplastic Polyurethane (TPU)
Polylactic Acid (PLA)	0.000420391	0.061746691	0.008673568	0.001334071	0.005705498	0.007574365	0.009703086	0.122459251	0.205739824	0.626875087	**1**	Polylactic Acid (PLA)
Polycarbonate (PC)	0.090083851	0.059754862	0.105321893	0.001334071	0.006846598	0.007574365	0.011643703	0.116851278	0.16710682	0.588491124	**2**	Polycarbonate (PC)
Rubber Compounds	0.066061491	0.064734434	0.043367838	0.001667588	0.002567474	0.003550483	0.006468724	0.11978642	0.156218128	0.565998382	**3**	Rubber Compounds
Polyethylene (PE)	0.090083851	0.048799804	0.009293108	0.000667035	0.003423299	0.003787182	0.007762469	0.156084954	0.134203441	0.462310734	**8**	Polyethylene (PE)
Ethylene Vinyl Acetate (EVA)	0.066061491	0.046807975	0.037172433	0.001334071	0.002282199	0.002840387	0.007115596	0.128240383	0.154032802	0.54568698	**4**	Ethylene Vinyl Acetate (EVA)
Kevlar Reinforced Composites	0.180167703	0.071705834	0.061954055	0.040022122	0.068465979	0.037871823	0.011643703	0.189912456	0.113873561	0.374847935	**9**	Kevlar Reinforced Composites
Polyether Ether Ketine (PEEK)	0.180167703	0.065730348	0.006195405	0.100055304	0.010269897	0.010414751	0.014231193	0.238170448	0.023226847	0.088856494	**11**	Polyether Ether Ketine (PEEK)
Fiberglass reinforced Plastic (FRP)	0.180167703	0.089632293	0.030977027	0.006670354	0.017116495	0.018935911	0.012937448	0.202161586	0.108119224	0.348456046	**10**	Fiberglass reinforced Plastic (FRP)
High Density Polyethylene (HDPE)	0.090083851	0.047305932	0.018586216	0.001000553	0.003423299	0.003787182	0.007115596	0.150987385	0.134474314	0.471076557	**7**	High Density Polyethylene (HDPE)

Fig. 5. Results for the inner non-metallic hoof pad part.

horse-drawn carriages emphasized the criteria of biodegradability, comfortability (weight and impact strength), economic viability (price), and durability (tensile strength, flexural strength, and hardness) as shown in Fig. 5. Biodegradability in the natural environment was considered the most important criterion, while hardness was the least important.
For the criteria weighting, the criteria were assigned the following weights: Biodegradability (natural environment) was 0.37806632, impact strength was 0.206712817, price was 0.153698507, tensile strength was 0.108064875, flexural strength was 0.072827841, hardness was 0.046627279, and weight was 0.03400236. Biodegradability was prioritized to ensure that the material chosen for the hoof pad was environmentally friendly and did not contribute to pollution when it eventually degraded. Impact strength was also crucial, as the material had to withstand the forces exerted during use. Price, while important, was balanced with the need for performance and durability.
For the material evaluation, the AHP-TOPSIS analysis yielded the following results for the various materials considered: Polylactic acid (PLA) ranked first with a score of 0.626875087. PLA stood out as the best option for the inner non-metallic hoof pad. Despite its low score in some durability-related criteria, its exceptional biodegradability and reasonable performance in impact strength made it highly suitable. PLA's environmental friendliness aligned with the goal of sustainable development, making it the top choice. Polycarbonate (PC) with a score of 0.588491124 ranked second. It offered a good balance between biodegradability, impact strength, and price, although it was less environmentally friendly than PLA. However, its strong performance in impact strength and tensile strength made it a viable option for the hoof pad.
Rubber compounds ranked third with a score of 0.565998382. They offered a good combination of impact strength and durability, particularly in flexural strength, making them a robust option. However, their biodegradability was lower compared to PLA and PC, which affected their ranking slightly. Ethylene vinyl acetate (EVA) with a score of 0.54568698 ranked fourth. It performed well in impact strength and weight but fell short in biodegradability, which was a key criterion. EVA's relatively low cost and good comfortability features made it an acceptable choice, but its environmental impact was a concern. Thermoplastic polyurethane (TPU) ranked fifth with a score of 0.53666658. It offered a good balance of impact strength, price, and durability, but, like EVA, it was less biodegradable, which limited its ranking.
Nylon (Polyamide) ranked sixth with a score of 0.521392402. Nylon performed moderately well across most criteria. Its biodegradability was relatively low, but it offered decent impact strength and durability, making it a reasonable choice for the hoof pad, especially if environmental impact was less of a concern. High-density polyethylene (HDPE) with a score of 0.471076557 ranked seventh. While it was cost-effective and durable, its biodegradability was limited, which lowered its overall ranking. Polyethylene (PE) ranked eighth with a score of 0.462310734. Its low cost and decent performance in some criteria were overshadowed by its poor biodegradability, making it less desirable for this application.
Kevlar reinforced composites ranked ninth with a score of 0.374847935. They offered high durability and impact strength but were very poor in terms of biodegradability, making them less suitable despite their strong performance in other areas. Fiberglass reinforced plastic (FRP) with a score of 0.348456046 ranked tenth. Its low biodegradability and higher cost, combined with moderate performance in other areas, made it less attractive for the hoof pad. Polyether ether ketone (PEEK) ranked last with a score of 0.088856494. Although it was highly durable and strong, its poor biodegradability and very high cost made it unsuitable for this application.
The outer part of the hoof pad is a critical component that must balance strength, durability, and weight. Utilizing CAD modeling, the design focused on achieving a lightweight structure with sufficient rigidity to withstand the demands of horse-drawn carriage operations. The material selected for the outer part is Aluminum Alloy (6061-T6) due to its excellent balance of mechanical properties, including high tensile strength and good corrosion resistance.
The CAD model of the outer part was subjected to a series of simulations to assess its performance under various load conditions. The results indicated that the aluminum alloy could sustain the required loads while maintaining a lightweight structure, thus reducing the overall weight that the horse must carry. Additionally, the alloy's good machinability allows for precise manufacturing, ensuring the structural integrity of the hoof pad.

The aluminum alloy's tensile strength, combined with its resistance to environmental factors such as moisture and chemicals, makes it an ideal choice for the outer part. The alloy’s lightweight nature contributes to a reduction in the overall load on the horse, which can enhance performance and reduce fatigue. The selection of Aluminum Alloy (6061-T6) for the outer part aligns with the goals of optimizing strength while minimizing weight. This choice is supported by the CAD analysis, which demonstrated the material’s capacity to meet the operational demands of horse-drawn carriages. However, considerations such as the potential for wear and the need for periodic maintenance should be addressed in future iterations of the design.
The inner part of the hoof pad is designed to provide comfort and support while ensuring that the horse’s hoof is protected from impact and strain. The CAD model for the inner part emphasizes ergonomic design, ensuring that the pad fits snugly around the horse's hoof to distribute pressure evenly.
The Analytical Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) were employed to evaluate and rank various non-metallic materials for the inner part of the hoof pad. The criteria considered included biodegradability, impact strength, price, tensile strength, flexural strength, and hardness.
Polylactic Acid (PLA) was ranked first with a performance index of 0.6269. PLA’s biodegradability and balance of mechanical properties make it a suitable choice for the inner part. It offers sufficient impact

resistance and tensile strength while being environmentally friendly. Polycarbonate (PC) was ranked second with a performance index of 0.5885. PC provides excellent impact strength and durability, making it a strong contender for applications where long-term use is expected. Rubber Compounds and Thermoplastic Polyurethane (TPU) were ranked third and fifth, respectively. These materials are known for their flexibility and comfort, which are crucial for the inner pad but have limitations in terms of biodegradability.

The CAD model of the inner part was tested for stress distribution and comfort under simulated conditions. PLA, being the top-ranked material, showed promising results in terms of fitting and pressure distribution. The model highlighted areas of potential stress concentration, which were mitigated by adjusting the design to better conform to the hoof's natural shape.

The use of PLA for the inner part of the hoof pad presents a sustainable solution that does not compromise on performance. The CAD analysis confirmed that PLA could provide the necessary protection and comfort for the horse's hoof. However, given PLA's lower durability compared to synthetic polymers like TPU, the inner pad may require more frequent replacement, which is a trade-off for its biodegradability.

The use of AHP-TOPSIS in the material selection process proved effective in balancing multiple criteria and identifying the most suitable material. Future research could explore hybrid materials or composite designs that combine the strengths of PLA with other polymers to enhance durability while maintaining environmental benefits.

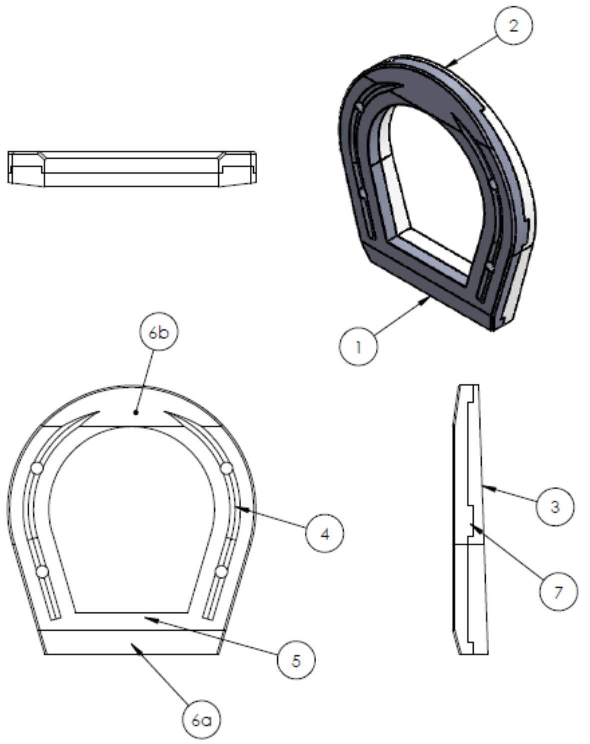
The figure shown below on Fig. 6, illustrates the assembly of the system, showing how the aluminum outer shoe and the PLA inner hoof pad fit together. It also details the integration of the straight bar type horseshoe design.

The outer part of the hoof pad was a critical component that had to balance strength, durability, and weight. Utilizing CAD modeling, the design focused on achieving a lightweight structure with sufficient rigidity to withstand the demands of horse-drawn carriage operations. The material selected for the outer part was Aluminum Alloy (6061-T6) due to its excellent balance of mechanical properties, including high tensile strength and good corrosion resistance.

The CAD model of the outer part was subjected to a series of simulations to assess its performance under various load conditions. The results indicated that the aluminum alloy could sustain the required loads while maintaining a lightweight structure, thus reducing the overall weight that the horse had to carry. Additionally, the alloy's good machinability allowed for precise manufacturing, ensuring the structural integrity of the hoof pad.

The aluminum alloy's tensile strength, combined with its resistance to environmental factors such as moisture and chemicals, made it an ideal choice for the outer part. The alloy's lightweight nature contributed to a reduction in the overall load on the horse, which could enhance performance and reduce fatigue. The selection of Aluminum Alloy (6061-T6) for the outer part aligned with the goals of optimizing strength while minimizing weight. This choice was supported by the CAD analysis, which demonstrated the material's capacity to meet the operational demands of horse-drawn carriages. However, considerations such as the potential for wear and the need for periodic maintenance were to be addressed in future iterations of the design.

The inner part of the hoof pad was designed to provide comfort and support while ensuring that the horse's hoof



FEATURE NO.	FEATURE DESCRIPTION	QTY.
1	CNC-machined aluminum outer shoe	1
2	3D-printed PLA inner hoof pad	1
3	Angled surface	
4	V-shaped crease	
5	Bar-shaped	
6a	Heel angled slide	
6b	Toe angled slide	
7	Male locking mechanism	

Fig. 6. 3D cad assembly drawing of the outer shoe and inner hoof pad

was protected from impact and strain. The CAD model for the inner part emphasized ergonomic design, ensuring that the pad fit snugly around the horse's hoof to distribute pressure evenly. The Analytical Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) were employed to evaluate and rank various non-metallic materials for the inner part of the hoof pad. The criteria considered included biodegradability, impact strength, price, tensile strength, flexural strength, and hardness.

Polylactic Acid (PLA) was ranked first with a performance index of 0.6269. PLA's biodegradability and balance of mechanical properties made it a suitable choice for the inner part. It offered sufficient impact resistance and tensile strength while being environmentally friendly. Polycarbonate (PC) was ranked second with a performance index of 0.5885. PC provided excellent impact strength and durability, making it a strong contender for applications where long-term use was expected. Rubber Compounds and Thermoplastic Polyurethane (TPU) were ranked third and fifth, respectively. These materials were known for their flexibility and comfort, which were crucial for the inner pad but had limitations in terms of biodegradability.

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The use of PLA for the inner part of the hoof pad presented a sustainable solution that did not compromise on performance. The CAD analysis confirmed that PLA could provide the necessary protection and comfort for the horse's hoof. However, given PLA's lower durability compared to synthetic polymers like TPU, the inner pad might require more frequent replacement, which was a trade-off for its biodegradability.

The use of AHP-TOPSIS in the material selection process proved effective in balancing multiple criteria and identifying the most suitable material. Future research could explore hybrid materials or composite designs that combined the strengths of PLA with other polymers to enhance durability while maintaining environmental benefits.

The figure shown below in Fig. 6 illustrated the assembly of the system, showing how the aluminum outer shoe and the PLA inner hoof pad fit together. It also detailed the integration of the straight bar-type horseshoe design.

5. CONCLUSION

The AHP-TOPSIS analysis highlighted that aluminum alloys (6061-T6) and magnesium alloy (AZ31B) were the top choices for the outer metallic part of the hoofwear, based on their strong performance in key criteria such as weight, impact strength, and abrasion resistance, balanced with cost considerations. Stainless steel (304) and mild steel (A36) also presented viable options, offering a good balance of performance and cost. Materials like titanium (Grade 5) and nickel alloy (Inconel 718), while high-performing, were less favorable due to their higher cost. The lower-ranked materials, including brass (C36000) and copper alloy (C11000), exhibited weaker performance in critical areas, making them less suitable for the application. This comprehensive evaluation ensured that the selected material would provide the best combination of durability, performance, and cost-effectiveness for the hoofwear's outer metallic part.

After evaluating the inner non-metallic hoof pad parts, the analysis indicated that polylactic acid (PLA) was the most suitable material for the inner non-metallic hoof pad, primarily due to its excellent biodegradability and sufficient impact strength. Polycarbonate (PC) and rubber compounds were also viable options, offering a balance between performance and environmental impact. However, materials like Kevlar-reinforced composites, fiberglass-reinforced plastic (FRP), and polyether ether ketone (PEEK), despite their superior durability, were less favorable due to their poor biodegradability and higher costs. The chosen material needed to strike a balance between environmental sustainability and performance, with PLA being the best choice for this specific application.

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