UNIVERSIDAD DE CHILE
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"BEHAVIORAL MATERIAL AND STRUCTURAL COMPARISON OF THE TRADITIONAL IRON HORSESHOE WITH THE INNOVATIVE COPPER ALLOY HORSESHOE"

CAROLINA JACQUELINE CARVAJAL MENESES

Memoir to qualify for the Professional Title of Veterinary Doctor
Department of Clinical Sciences

GUIDE PROFESSOR: Dr. MARIO NELSON ACUÑA BRAVO

SANTIAGO, CHILE
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FINAL GRADE:. . . . .

		GRADE	SIGNATURE
GUIDE PROFESSOR	: DR. MARIO N. ACUÑA BRAVO	. . . .	. . . .
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TITLE OF MEMOIR

"BEHAVIORAL MATERIAL AND STRUCTURAL COMPARISON OF THE TRADITIONAL IRON HORSESHOE WITH THE INNOVATIVE COPPER ALLOY HORSESHOE"

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Summary

According to the old proverb "Without a hoof there is no horse", throughout the years, the shoeing continues to be the fundamental procedure for the protection of the hoof. The objective of this study was to compare the effectiveness of using the iron and copper alloy horseshoe, evaluating its structural behavior, wear, attenuation and impact transmission, after a period of shoeing. A practical study was carried out with 12 clinically healthy crossbred horses in similar physical and environmental conditions. Six horses were selected at random, to be shod on their right limbs with iron and on their left limbs with copper alloy and the other six copies in reverse arrangement. The percentage (%) of wear on a digital weight (grams) was evaluated, determining the weight loss of each shoe. The identification and quantification of structural damage such as fissures or cracks was carried out by means of a kit of three aerosols. Likewise, a mathematical model was developed, which was implemented in the form of a three-dimensional animation with the help of a computer program, evaluating the damage produced up to the distal interphalangeal joint. As a result, it was obtained that the copper alloy horseshoe transmits a lower impact force (8.56%) compared to the iron horseshoe. In addition, it has a lower resistance to wear (9.07%) compared to iron (5.07%) and no structural damage such as cracks or fissures were observed inside each shoe, which shows that this innovative shoe based on copper, can be used on equal terms with iron.
Keywords: Hoof, Hardware, Iron and copper alloy horseshoes, Wear, Structural damage, Impact force.

Abstract

According to the old adage "No hoof no horse", along the years, the horseshoeing remains as the fundamental procedure for hoof protection. The objective of this study was to compare the efficacy of using iron and copper alloy horseshoes, evaluating structural behavior, wear attenuation and transmission of impact, after a horseshoeing period. It was made a study with 12 clinically healthy horses in similar physical and environmental conditions. Randomly were selected six horses to wear iron horseshoes in their right hooves, and copper alloy in their left hooves and an inverse disposition the other six horses. There were evaluated the percentage (%) of wear with a digital weight (grams), to determine the weight loss of each horseshoe. It was performed the identification and quantification of structural damage such as cracks or fissures using a kit of three sprays. Also it was developed an mathematical model, in the form of three-dimensional animation with the support of a computer program, assessing the damage to the distal interphalangeal joint. The result was that the copper alloy horseshoe transmits less force of impact (8.56%) compared with the iron horseshoe. Also, has a lower wear resistance (8.52%) compared to iron (4.42%) and there was no structural damage like cracks or fissures within each horseshoe, demonstrating that this innovative horseshoe base copper can be used on equal term that the iron.
Keywords: Hoof, Horseshoeing, Iron and copper alloy horseshoes, Wear, Structural damage, Impact force.

INTRODUCTION

In current conditions, in which the equine is used for work, recreational activities, or in various sports disciplines, it is absolutely essential that the animal is shod (Houghton et al., 2003). Many veterinarians and people related to equestrian activity coincide in stating that "without a hoof there is no horse", for which it is totally necessary to know the anatomy, physiology and biomechanics of this elemental structure of the animal, as well as the poise and the technique of hardware (Baeza, 1992).

The horse's hoof is a highly specialized anatomical unit that constitutes an expression of biomechanics, and in order for it to fulfill its function in good shape, it must be constantly in optimal condition, since it must withstand great pressures and efforts that the horse is forced to exert. perform daily. In this sense, the hardware has a determining role for the performance, health and useful life of each specimen (Berríos et al., 1995).

The hoof fitting is carried out periodically, being a process that must be carried out by a qualified farrier and under the supervision of a specialist veterinarian every four to six weeks to maintain an adequate conformation and balance of the hooves (Myers, 2005).

Anotomy and Conformation of the Hoof

The horse's foot is a complex structure composed of the third phalanx, the middle of the second phalanx, the distal sesamoid bone, the distal interphalangeal joint, the tendon termination of the common digital extensor tendon and the deep digital flexor tendon, plus irrigation and innervation. . In turn, the hoof is divided into the limbus, crown, wall, white line, sole, ungular pad, frog, heels and bulb of the heels, respectively (O'Grady, 2008).

Horseshoe

The horseshoe is a semicircular shaped piece of metal that is fixed to the hoof by means of nails. These can be of different materials, such as iron, steel, aluminum, alloys and even plastic; differing in weight, durability, resistance to wear, attenuation of forces and in cost (Stashak, 2004).

The horseshoe is divided in turn, into branches, heels, boards, edges, nails and grooves and is essential as a means of protection, because its main function is to protect the hoof from injuries and intense wear and tear to which it is subjected. It also provides greater traction, improves support and balance, is used as a correction treatment in many conformation problems and a particular pathological condition (O'Grady, 2008).

The horseshoe must be adapted to both the shape and size of the hoof, being wide and long enough, so that the hoof has maximum support and maximum expansion. However, before being positioned correctly, it is necessary to perform adequate trimming and trimming to keep the structure, angle and axis of the hooves as close to normal as possible (Houghton et al., 2003). This is especially relevant, since improper shoeing practices can induce poor hoof conformation and can be the cause of the presentation of various musculoskeletal and / or osteoarthritic pathologies, generating the shortening or cessation of the useful life of equines. (Stashak, 2004).

At present, iron continues to be the metal most frequently used in the manufacture of horseshoes, mainly due to its ease of finding it in the market and its cheaper price (Procobre, 20071). However, it has some disadvantages such as the low attenuation of forces that are released from the iron when impacting against the ground in the support, which may affect the integrity of the anatomical structures contained within the capsule of the hoof and others at an immediately higher level (Back, 2001).

In recent years, numerous investigations have been carried out that have determined that copper and its alloys have multiple benefits, among which are: possessing bactericidal and fungicidal properties, preventing the proliferation of bacteria and fungi; and reduce low intensity trauma, minimizing damage to the locomotor system (Procobre, 2007).

Biomechanical Effects of the Hoof

The biomechanics of the equine foot focuses on the effects on the distal limb and the nail capsule. During locomotion an elaborate mechanism of the fibroelastic apparatus of the hoof is triggered, which consists of

[1] PROCOBRE is a network of Latin American institutions whose mission is to promote the use of copper, promoting research and development of new applications and disseminating its contribution to the improvement of the quality of life and the progress of society.

attenuate the forces it receives each time it hits the ground surface. This mechanism implies that the dorsal wall, heels, nail pad and the frog expand laterally and caudally and the sole decreases its concavity. During the suspension phase, the mentioned structures return to their original position, due to the damping characteristics and the elastic deformation capacity of the nail capsule (Thomason, 2009).

Throughout the impact, the member is subjected to an external impact force that comes from the ground. This impact is called the ground reaction force (GRF), whose magnitudes and distribution of stresses depend on various factors, such as gait, type and speed of exercise, balance of the hull, surface of the ground and the hardware technique (Back, 2001). The main effect of this force is to be transmitted towards the capsule of the hoof and its internal anatomical structures, having potentially damaging effects on the bones and joints, since they are the structures most susceptible to these low intensity and repetitive traumas over time. compared to soft tissues (Clayton, 2004). However, there is still no knowledge of the amount of force that attenuates each structure (Back, 2001).

This force acts at a single point, called the center of pressure (CoP, "center of pressure") or point of zero moment (PZM, "point of zero moment") that is located near the vertex of the frog (Back, 2001) . Therefore, the repeated application of this force will overload the extremities, and may lead to the development of future pathologies, such as navicular syndrome, fractures, degenerative joint disease, among others, having implications for performance and useful life in the activity carried out by the specimen (Clayton, 2004).

At present, it is not possible to determine the biomechanical functions of most of the anatomical structures that make up the hoof. Knowing these functions is an essential requirement to be able to understand the causes of a biomechanical injury and thus be able to prevent this type of injury (Thomason, 2009).

Copper Alloy Horseshoe

Copper is a metal that has excellent behavior and elasticity; high adaptability; high durability, malleability and manufacturing capacity (Codelcoeduca, 20112); good resistance to corrosion and wear

(Jiménez, 2006); easily recyclable; high capacity metal alloy; high resistance when used hot and / or cold; with bactericidal, fungicidal and impact attenuation properties. However, pure copper has the characteristic of being a very soft metal, deforming or breaking more easily (CEDIC, 2007). For this reason, in recent years different copper alloys have been developed that manage to improve the mechanical properties of the metal, without reducing its antimicrobial properties (Codelcoeduca, 2011).

In a study carried out in the Microbiology Laboratory of the Institute of Nutrition and Food Technology (INTA) of the Universidad de Chile, in conjunction with the Veterinary Section of the Cavalry Squadron of the Military School of the Chilean Army in 2003, on the antimicrobial activity of the iron and copper alloy horseshoe in the presence of bacteria and fungi in the horse's hoof, it was shown that the use of copper alloy horseshoes achieve a drastic decrease in foot pathologies by generating a constant release of copper salts, which act on the aerobic and anaerobic bacteria that colonize these structures, as well as on the fungi that contribute to the problem and that together generate serious structural damage that frequently makes it impossible for the equine to develop its usual activity (Rivas et al. al., 2003).

Likewise, the Institute of Materials Research and Testing (IDIEM), dependent on the Faculty of Physical and Mathematical Sciences of the Universidad de Chile, carried out a functional study through the comparative analysis of the behavior of the iron and copper alloy horseshoe, to through the Charpy Impact test and abrasive wear. The result of this study showed that the use of a copper-based horseshoe mitigates impact forces and has good resistance to material wear. These results have shown favorable antecedents for the replacement of iron by copper in horse shoes, indicating a new market opportunity for the national copper industry (Rivas et al., 2003).

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[2] Codelcoeduca, an educational website belonging to CODELCO, is an autonomous company owned by the Chilean State, whose main business is the exploration, development and exploitation of copper mining resources and by-products, their processing into refined copper and their subsequent commercialization.

Based on this information, the objective of this title report is to compare the effectiveness of using two types of horseshoes, the traditional iron shoe with an innovative copper alloy shoe, evaluating its structural behavior and its behavior in terms of wear. , attenuation and transmission of impact forces, after a period of shoeing (45 days), with the final purpose of having an alternative for the prevention and treatment of traumatic processes that affect the hooves and therefore, the useful life of the horse, respectively.

MATERIAL AND METHODS

Study location

The studies of structural damage and wear of the material were carried out in 12 mestizo horses, belonging to the Squadron of the Equestrian Center of the Artillery Regiment No. 1 "Tacna" in the commune of San Bernardo, Metropolitan Region. For this, copper-based horseshoes with the following alloys were used: Copper-Zinc-Aluminum Manganese-Iron (83.5, 15, 1, 0.25, 0.25%, respectively), thus obtaining an optimization of the mechanical properties and an increase in hardness (Figure 1). This type of horseshoe was designed and provided by the Kawell3 company.

Figure 1: Copper Alloy Horseshoes

The study of attenuation and transmission of impact of the material was carried out in the dependencies of the Department of Mechanics of the Faculty of Engineering of the University of Santiago de Chile, through a computer program.

Selection of clinically healthy specimens

A practical study was carried out choosing 12 clinically healthy horses, without distinction of sex, which were in similar conditions, both physical and environmental. Within the physical conditions the weight, race, body texture, balance and conformation of the hooves were determined. Regarding the

[3] First Company of Copper Alloy Horseshoes in Santiago de Chile, 2011.

environmental conditions, the type of soil, infrastructure and work performed were determined. The horses included in the sample had a body weight between 540 and 560 kilos, mongrels, with adequate poise and hoof axes, housed on a cement floor, with daily activity on a surface of land and grass, used for jumping and training.

During the study, six horses were randomly selected to be shod the right anterior and posterior hooves with iron horseshoes and the left anterior and posterior hooves with copper alloy horseshoes and the other six specimens in reverse arrangement, after trimming and stripping of the hooves. This uneven distribution of the horseshoes on each side of the specimen was made because the right and left halves of the animal could have different weights, due to the different anatomical distribution of its organs. Therefore, the purpose of this form of distribution was to be able to determine the study in similar anatomical conditions.

This practical study was carried out in a period of shoeing that corresponds to 45 days, where the percentage (%) of wear was evaluated and the identification and quantification of structural damage in the two types of horseshoes was carried out.

Structural study

The structural study was carried out with the purpose of identifying and quantifying the existence or absence of possible structural damages such as cracks or fissures inside each horseshoe (iron and copper alloy), once the period of ironing was finished.

In order to carry out this procedure, a macroscopic analysis was carried out on the horseshoes by means of penetrating inks found in a kit of three aerosols; a cleaner, a penetrating liquid and a developer agent (Figure 2), developed as follows: the surfaces of each shoe were cleaned with the cleaner (Crick 110), to then be able to spray a thin layer of the penetrator (Crick 120) until the entire area is covered. Subsequently, the penetrant was left to dry for 20 minutes, the excess product was removed with water to finally apply a thin and homogeneous layer of the developer (Crick 130), allowing it to act. If this test was positive, that is, if the ink penetrated the horseshoe material, this was indicative that the horseshoe had some kind of fracture in its structure. Next, a table was made, which was divided into the name of the animal, the number of fractures per limb and the position of each horseshoe.

Figure 2: Kit of three aerosols. Cleaner (Crick 110), Penetrator (Crick 120) and Developer (Crick 130).

With this study, the tensile strength (force/area), hardness and toughness of each material were evaluated. Tenacity is the resistance that a body opposes to deform or break (Jiménez, 2006).

Material behavior study

This study consisted of determining the percentage (%) of wear and the percentage (%) of attenuation and transmission of impact, in order to evaluate the mechanical properties of the horseshoe on the integrity of the hoof.

a) Percentage (%) of wear: the resistance to wear was determined through the loss of weight of each shoe. Before and after 45 days, each type of horseshoe (one made of copper alloy and one of iron) was weighed in a precision instrument, which consists of a digital weight, where the weight in grams was obtained (Figure 3). Once the weight of the horseshoes was obtained, the results were recorded in two tables (beginning and end of the shoeing period), indicating the name of the animal, number, weight and position of each shoe. Subsequently, with the total data, the wear percentage (%) was determined, recording it in two tables, one for each type of shoe.

Figure 3: Digital weight. Weight in grams.

With this study, the resistance to wear, hardness and durability of each shoe was evaluated.

b) Percentage (%) of impact attenuation and transmission: this study was carried out in order to determine the attenuation and transmission of forces produced by each horseshoe during the support phase on the ground surface.

In order to carry out this study, a mathematical model called "Impact Model" (Figure 4) was developed, based on the "Damping Spring Mass System" (Annex 1), which was later implemented in the form of a three-dimensional animation with the help of a computer program called "MSC. Visual Nastran 4D ™ 4" (Figure 5), developed as follows: three main components were considered, the horseshoe (X0); the hoof (X1) and the rest of the horse mass (X2). Between X0 and X1, two constants were found that correspond to the stiffness of the horseshoe (K1) and the cushioning of the horseshoe (C1). Then, between X1 and X2, two constants were found pertaining to the stiffness of the hoof capsule and bone structures (third phalanx, half second phalanx, distal sesamoid bone) (K2) and cushioning of the hoof capsule and bone structures (C2). Each of these components are linked by springs and shock absorbers, transmitting forces from one element to the other. These were quantified and therefore the comparative behavior was determined in percentage form.

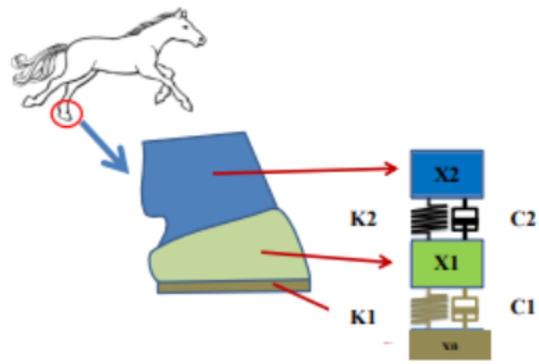


Figure 4: Impact Model. **(X0)** Horseshoe; **(X1)** Hoof; **(X2)** Rest of the horse mass. **(K1)** Horseshoe stiffness constant; **(K2)** Stiffness constant of the hoof capsule and bone structures. **(C1)** Horseshoe damping coefficient; **(C2)** Damping coefficient of the hoof capsule and bone structures.

Before developing this computational study, mechanical factors such as: modulus of elasticity, coefficient of restitution, damping constants and stiffness of the horseshoes, hoof capsule and bone structures had to be determined; and geometric factors such as: horse mass, mass of the hoof capsule with its internal anatomical structures (bone), mass of each horseshoe, length, diameter of the hoof and bones. The values of each of these constants (stiffness and damping) have been determined from the different mechanical factors, the

[4] MSC. Visual Nastran 4D ™ from MSC Software. 2003, is a tool for the mechanical engineer that combines kinematic simulation with stress analysis under a single modeling environment, in order to ensure the dynamics of their assemblies before being manufactured and determine if the parts will withstand operating conditions, without the need to test physical prototypes.

that have been modified according to their geometry (Annex 1).

After entering these data into the computer program, the components were dropped onto a rigid surface, and with this action the response to impact between the two horseshoes was evaluated.

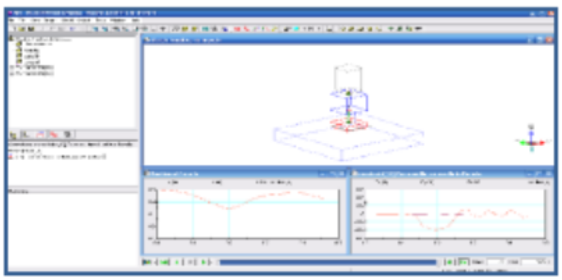


Figure 5: Computer program "MSC. Visual Nastran 4D ™ 4"

Once the computer program solved the mathematical equation of the "Damping Spring Mass System", the results of this impact were recorded in three graphs. Each graph represents the horse's gait phases, determining the time of maximum support (maximum force). In the graph called "Ground-Horseshoe Contact Force", it was developed with the objective of comparing the percentage (%) of impact force produced between the two horseshoes. Later, another graph called "Horseshoe-Hoof Force" was developed, in order to compare the percentage (%) of force transmitted to the hoof capsule and bone structures and the percentage (%) of attenuated force for each horseshoe under study. Finally, by means of a graph called "Hoof Force-Rest of Horse Mass", the percentage (%) of force that is transmitted to the rest of the horse mass was compared, which comprises from the proximal interphalangeal joint upwards. Each graph is made up of two variables (force / time) and two solid lines are displayed that represent the two types of horseshoes.

With this study, the structural effect produced by the use of a horseshoe based on an alloy of copper and another of iron was quantified in a comparative way, knowing the forces that are generated in both horseshoes under the same movement condition.

Statistic analysis

In the case of the percentage (%) of wear, the Wilcoxon test was used, a non-parametric statistical test based on the analysis of data from two related samples, considering the relative magnitudes of the differences as well as their signs. The null hypothesis (HO: E (X) = E (Y)) was considered, with 95% confidence, 5%

error and level of significance (P≤0.05). To this end, the wear of each type of shoe (beginning and end of the shoeing period) and the difference in wear between the two were compared. At the beginning of the period, the copper alloy presented an average in grams (329.92); median (331); standard deviation (SD) (22.32) and coefficient of variation (CV) (6.76); and iron, an average in grams (289.83); median (285); DE (15.42) and CV (5.32). At the end of the period, the copper alloy presented an average in grams (301.79); median (296); DE (18.09); CV (5.99); and iron an average in grams (277); median (278); DE (16.01); CV (5.78), respectively.

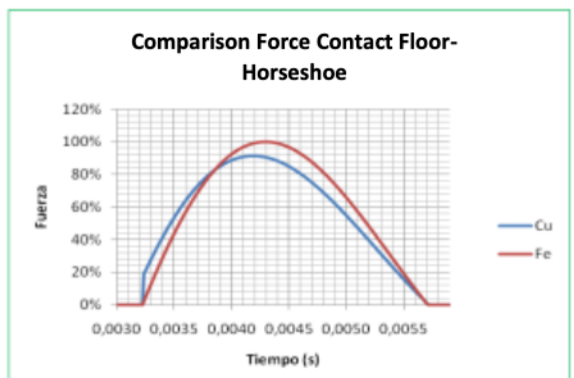
RESULTS

Percentage (%) of impact attenuation and transmission

Once the three-dimensional animation was carried out based on a mathematical model, adapted to real conditions and with the help of a particular computer program, it was possible to establish by means of graphics the results of percentage (%) of attenuation and transmission of reaction force that They are generated in each of the components under study, from the entry of geometric and mechanical data of the structures, which were later integrated using the equation of the "Damping Spring Mass System". Firstly, the impact forces between the ground and the shoe are presented, secondly, between the shoe and the hoof and, thirdly, between the hoof and the rest of the horse.

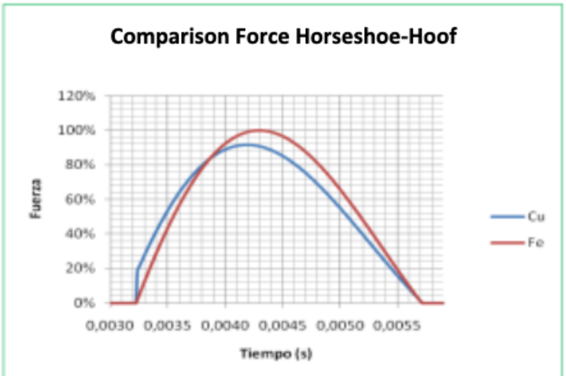
In Graph 1 it can be observed that the copper alloy horseshoe transmits a lower impact force (GRF), 8.56%, compared to the iron horseshoe, because this horseshoe manages to attenuate 8.56% of the GRF.

Graph 1: Percentage (%) of reaction force produced by the contact between the ground and each type of shoe (Cu/Fe).



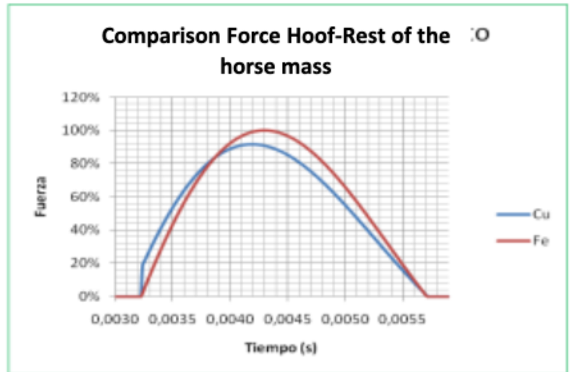
In Graph 2 it can be seen that the copper alloy horseshoe transmits a lower percentage of force towards the hoof capsule and internal anatomical structures, due to the fact that it presents higher attenuation, 8.54%, compared to iron horseshoe.

Graph 2: Percentage (%) of reaction force transmitted and attenuated by each horseshoe (Cu / Fe).



In Graph 3 it can be seen that the copper alloy horseshoe transmits 8.53% less force to the rest of the horse mass, corresponding from the proximal interphalangeal joint upwards.

Graph 3: Percentage (%) of reaction force transmitted to the rest of the horse mass, for each type of horseshoe (Cu/Fe).



In Table 1, a summary of the maximum forces (time of maximum support) of each horseshoe towards the three components of the model is shown.

Table 1: Summary of the maximum values obtained in each of the component interactions.

	Floor-Horseshoe	Horseshoe-Hoof	Hoof-Rest of horse mass
Maximum force Cu	91.44	91.46	91.47
Maximum force Fe	100	100	100
% Difference Maximum Force	**8.56%**	**8.54%**	**8.53%**

91.44
91.46
91.47

Wear percentage (%)

After weighing the horseshoes in a digital instrument and obtaining the weights in grams, before and after the 45-day shoeing period, it was possible to compare the percentage (%) of wear of each shoe (iron and copper alloy) and of each limb (anterior and posterior) respectively.

Table 2 shows the weights (grams) at the beginning of the fitting period. It is observed that the copper alloy horseshoe weighs on average 40 grams (12%) more than the iron one.

Table 2: Weights (grams) at the beginning of the fitting period.

Nº	Weight Cu+ MA - MP	Weight Fe+ MA – MP	Position Cu+	Position Fe+
1	333 - 335	310 - 310	LEFT	RIGHT
2	323 - 326	271 - 280	LEFT	RIGHT
3	303 - 296	285 - 276	LEFT	RIGHT
4	348 - 350	301 - 305	LEFT	RIGHT
5	325 - 326	282 - 279	LEFT	RIGHT
6	344 - 345	295 - 286	LEFT	RIGHT
7	329 - 328	285 - 278	RIGHT	LEFT
8	361 - 364	305 - 308	RIGHT	LEFT
9	338 - 337	295 - 294	RIGHT	LEFT
10	304 - 305	275 - 276	RIGHT	LEFT
11	308 - 296	282 - 272	RIGHT	LEFT
12	360 - 357	312 - 316	RIGHT	LEFT

MA: anterior limb/MP: posterior limb.

Table 3 shows the weights (grams) at the end of the fitting period. It is observed that the copper alloy horseshoe weighs on average 25 grams (8%) more than the iron one.

Table 3: Weights (grams) at the end of the fitting period.

Nº	Peso Cu+ MA - MP	Peso Fe+ MA - MP	Posición Cu+	Posición Fe+
1	309 - 298	298 - 296		
2	291 -296	260 - 266	IZQ	DER
3	283 - 254	278 - 261	IZQ	DER
4	329 - 318	294 - 294	IZQ	DER
5	291 - 296	265 - 233	IZQ	DER
6	342 - 296	294 - 285	IZQ	DER
7	320 - 312	286 - 276	DER	IZQ
8	308 -296	288 - 275	DER	IZQ
9	308 - 296	282 - 272	DER	IZQ
10	278 - 296	260 - 256	DER	IZQ
11	308 - 296	264 - 270	DER	IZQ
12	326 - 296	295 - 278	DER	IZQ

Tables 4 and 5 show the total weights of each type of shoe at the beginning and end of the shoeing period. It is observed in Table 4 (copper alloy) that the total weight difference is 721 grams, corresponding to 9.07% wear. In addition, it is observed that the hind limbs wear 121 grams (3.07%) more than the forelimbs.

On the other hand, in Table 5 (iron) it is observed that the total difference in weight is 354 grams, which corresponds to 5.07% wear. In addition, it is observed that the hind limbs wear 82 grams (2.38%) more than the forelimbs. According to the statistical analysis, the wear of the copper and iron alloy horseshoe is significant ($Z = 4.06$ and 3.47; $P \leq 0.05$). Likewise, the difference in wear (4%) between both shoes is also significant ($Z = 3.31$ $P \leq 0.05$).

Table 4: Total weights and percentage (%) of wear of the copper alloy horseshoe at the beginning and end of the shoeing period (24 horseshoes).

Hardware Period	Cu+ MA	Cu+ MP	Total
Total weight (grs) Start	3976	3965	7941
Total weight (grs) End	3676	3544	7220
Difference Grams	300	421	721
Percentaje (100%)	7.54	10.61	9.07

Table 5: Total weights and percentage (%) of iron shoe wear at the beginning and end of the shoeing period (24 horseshoes).

Hardware Period	Cu+ MA	Cu+ MP	Total
Total weight (grs) Start	3499	3480	6979
Total weight (grs) End	3363	3262	6625
Difference Grams	136	218	354
Percentaje (100%)	3.88	6.26	5.07

Structural Study

Once the macroscopic analysis was carried out using the three-spray kit (cleaner, penetrating liquid and developer), no structural damage such as cracks or fissures were observed inside each horseshoe (iron and copper alloy), once the period ended. of hardware.

Figure 6: Structural study of the 48 horseshoes under study.

DISCUSSION AND CONCLUSIONS

The antibacterial and antifungal capacity of the copper alloy horseshoe turned out to be an important part of the considerations by which the United States Environmental Protection Agency (EPA) certified copper as the first bactericidal metal in March 2008 (Procobre, 2007).

Within this alloy, copper (83.5%) and zinc (15%), provide the characteristic of elasticity, release of copper salts, resistance to wear and cold work (CEDIC, 2007); aluminum (1%) provides lightness (Jiménez, 2006); manganese (0.25%) and iron (0.25%) provide hardness and toughness (Rodríguez, 2007).

The use of copper alloy horseshoes have the characteristic of having a greater attenuation and lower transmission of impact force towards the components of the model (8.56%), compared to the iron horseshoe, observing a slight dissipation of the magnitude of strength as progress is made in the union of these components (Gutiérrez, 2011).

This attenuation significantly reduces the low intensity and repetitive traumas over time that are generated after each impact of the horseshoe with the ground. This is mainly due to the better mechanical properties that it presents, being fundamental the capacity of elasticity, damping and malleability of copper and its alloys, with respect to the iron with which horseshoes have traditionally been made. These characteristics of the copper alloy ensure that a large part of the reaction forces that are generated after impact are mitigated by the shoe and therefore, the forces transmitted to the hoof and to other anatomical structures of the hoof are minimized. equine, managing to reduce numerous unrecoverable pathologies that lead to the premature inability of many equines to continue developing their sports, recreational or work activities.

If we consider that the hoof when exerting the support, generates an action and reaction force on the ground and since this movement must be carried out by the horse, when using a copper-based horseshoe that has a lower magnitude of action and reaction force on the hoof, the horse will be saving this magnitude of force. From the energy point of view, if two horses run at the same speed and have similar characteristics, it is obtained that the horse that uses copper-based horseshoes uses less energy for each step than the one that uses iron shoes. Based on this, by using less energy he will have physical reserves that he can use to increase his long-term performance (Gutiérrez, 2011).

This attenuation percentage (%) will be proportional to the physical and environmental conditions in which the specimen is found, because the mechanical properties of metals and anatomical structures do not vary (Gutiérrez, 2011).

Although copper alloy horseshoes have a lower resistance to wear due to their high elasticity, such wear did not affect their structural resistance, hardness and durability, being similar to iron horseshoes, which gives them great qualities to be used in any type of terrain or specimen. Likewise, as it does not present any type of structural damage, it is shown that this innovative copper-based horseshoe has high resistance to different stresses and good toughness, so it can be used under equal conditions as iron.

The copper alloy horseshoes are completely adaptable to a special fitting condition or to an orthopedic use, thus being able to correct conformation problems, therapeutic handling or adapt to the function that the horse performs.

Among the additional advantages that copper alloy horseshoes have, their recyclability stands out. These horseshoes are 100% recyclable with economic retribution for the return, they reduce the costs for pathologies associated with the hoof, they eliminate 99% bacteria and fungi in the short term, reducing the time of the equine outside its sports activity, they have the property of attenuation impact and are a unique alloy in the world (patented in Chile and abroad) (Codelcoeduca, 2011). It also contributes to the protection of the environment, because hot fittings require less thermal application than iron (450º v / s 750º C), which has a favorable influence on reducing the carbon footprint towards the environment. Likewise, it presents a high malleability, flexibility and resistance, so they can be worked cold, without implying a lower structural resistance compared to traditional iron, achieving a notable saving of time with each hardware and a notable improvement in their quality. by allowing a better adaptation of the shoe to the hoof. In addition, the hooves become harder, with greater consistency and less humidity, which makes it easier to remove the palms and prevent future hoof pathologies.

All these characteristics allow copper alloy horseshoes to be used in different equestrian disciplines such as horse riding, enduro, rodeo, polo, improving the living conditions of equines and thus prolonging their useful life (Codelcoeduca, 2011).

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Modulus of elasticity (E): it is the ratio between the increase in pressure (force) and the change corresponding to the deformation of the material (Martínez and Azuaga, 1997).

$$E = \frac{\sigma}{\epsilon} = \frac{F/S}{\Delta L/L}$$

E = modulus of elasticity

σ = pressure (force) exerted on the cross-sectional area of the object (tensile test)

= strain

F = force

S = surface (area)

ΔL = variation in length

L = length at a given force

Damping spring mass system: it is the study of the movement of a mass attached to a support through a spring and a damper, for the analysis of dynamic systems (Ardila et al., 2009).

F = kx + cv ó m x''(t) = k x(t) + c x'(t)

F = impact force

k = stiffness constant

x = coordinate shift

c = damping coefficient

v (x '(t)) = velocity

m = moving mass

x '' (t) = acceleration

Coefficient of restitution: it is the ratio between the relative velocity of departure (final), and the relative velocity of approach (initial) of the collision between two bodies, whose difference is the absorbed energy (Anon, 2006).

$$e = -\frac{V_{2f} - V_{1f}}{V_{2i} - V_{1i}}$$

e = coefficient of restitution

Vf (2,1) = velocities of the bodies after the collision

Vi (2,1) = velocities of the bodies before the collision

Stiffness constant: it is the quantification of the stiffness of an element under a certain force, without acquiring large deformations (Pérez et al., 2005).

$$K = \frac{EA}{L}$$

K = stiffness constant
E = modulus of elasticity
A = diameter
L = length

Damping constant: it is the quantification of the damping of a body under a certain force (Sancho, 2010).

$$C = 2\sqrt{mred \times k}$$

C = damping coefficient
mred = reduced mass
k = stiffness constant