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ANALYSIS OF THE THERMAL BHEAVIOR OF CERAMIC SEMIMETALLIC AND ORGANIC BRAKE PADS AS A FUNCTION OF THE BRAKING DISTANCE UNDER THE ECE - 13H REGULATION

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Abstract—

The aim of this research was to analyze the thermal behavior of organic, semi-metallic and ceramic brake pads as a function of the stopping distance according to international standards. The chemical formulation of each of them is identified by micrography. The experimentation is carried out from the selection of the vehicle of the categories M1, N1. It is based on statistics from the AEADE and the selection of marketable brake pads in the Ecuadorian market that comply with the INEN 2185 Regulation. These pads are subjected to braking tests, the procedure and the selection of the necessary parameters for the braking tests are based on the ECE 13 - H regulation, verifying the minimum standards that are detailed there. The data is collected by means of a pyrometer and stored for statistical analysis to determine the behavior of the temperature generated in the brake pads with the different treatments. A variation of 34.49 °C in the organic type, 48.64 °C in the semi-metallic type and 52.98 °C in the ceramic was obtained. To validate the experiment, a multiple comparison analysis is performed using ADEVA to the temperature and stopping distance data of the treatments. The result is a probability ≤ 0.0001 for the validation of the null hypothesis. Thus, the alternative hypothesis was affirmed, the data was reliable, and the study validated. It is concluded that ceramic-type pads offer better performance with a temperature of 78.92 °C when braking at a braking speed of 50 km/h and 127.56 °C at a braking speed of 100 km/h, it was obtained an efficient braking distance at different initial braking speeds. It is recommending the use of ceramic type pads that guarantee the safety of the vehicle occupants.

Keywords— Brake system; Brake pad; Braking distance; Micrography; Coefficient of friction.

I. INTRODUCTION

In recent years, the national vehicle fleet has registered an average annual increase of 11.03% in the period 2008-2017 according to the National Transit Agency.(*TTITULO Anuario de Transporte*, 2016), Activity in the spare parts subsector is fully influenced by factors such as the number of vehicles that exist in the country,

the age of the mobile park, the price of new cars and, especially in the case of Ecuador, import tariffs new cars, parts, spare parts and spare parts.(Cremades & Bianchi, 2016). In recent years, the national vehicle fleet Among the most important spare parts are the components of the brake system such as: jaws, discs, pads and brake fluid. Which directly influences the active safety of the vehicle, consequently ensures the integrity of passengers.(Han & goleman, daniel; boyatzis, Richard; Mckee, 2019), In the automotive industry different types of brake pads are marketed that varies according to their cost, origin and type of material. Among the various types of brake pads found on the market are organic, semi-metallic and ceramic that each have specified properties.(Carrillo, 2015), There are traffic accidents for various reasons and one of them are the mechanical failures in the braking system due to the elevation of temperature resulting from the friction between the pickup and the brake disc, causing common problems such as: crystallization, cracking of the coating material, detachment of the material among others, these problems cause it to lose the mechanical properties , thus causing inefficient braking.(Smith, 2016)

Braking effort should ideally be distributed between the front and rear wheels depending on the weight they support, this weight varies depending on the position of the engine, number and distribution of occupants and luggage Depending on where the load is, the tires have more grip as they are crushed as can be seen in (C). Therefore, the brakes are provided in such a way that they act more intensely on the front wheels, since their greater adhesion to the ground keeps them from being blocked. Braking is effective as long as the wheels do not lock, i.e. as long as the wheels continue to rotate. It should not be forgotten that the brakes reduce the speed of the wheels, but it is really the tyres that stop the vehicle. If excessive braking locks the wheels, the deck will slide onto the pavement, resulting in loss of control of the vehicle.(Bauzá, 2018), For this reason for the automotive industry safety has been one of the most important pillars in the development of different types of pickups focusing on the development of new friction materials to achieve better efficiency and control of the vehicle, in this way it is possible to reduce accidents.

II. METHODOLOGY

This type of research is one of the most important quantitative research methods with a scientific approach, applying the senses as part of the observation, it is the change of dependent variable while manipulating the independent variable to check the validity of the hypothesis.(Technische Universtität München, 2018).

Techniques and data collection according to the Regulation ECE 13 - H

Techniques for data collection shall mean the procedure to be carried out to obtain data on the test carried out, in accordance with Regulation No 13-H of the United Nations Economic Commission for Europe (ECE) - Uniform provisions on the type-approval of passenger vehicles with regard to braking [2015/2364]. According to the regulations created by UNECE, with the last revision in 2015, it determines the efficiency of the braking system, through the braking distance and the average deceleration established, the regulation applies to vehicles of category M1 and N1, in the document also, there are definitions related to the braking system and its characteristics. (Oficial et al., 2016).

Vehicle category M

Motorized vehicles with capacity no more than eight seats, not counting the driver's seat(NTE INEN 2656, 2016). This type of vehicle is that it was used for the study, specifically the chevrolet aveo family automotive with high level of sale in Ecuador.

Category M. Four-wheeled or more motor vehicles designed and built for passenger transport. **M1:** Vehicles of 8 seats or less, not counting the driver's seat. **M2:** Vehicles with

more than 8 seats, not counting the driver's seat and gross vehicle weight of 5 tons or less. **M3:** Vehicles with more than 8 seats, not counting the driver's seat and gross vehicle weight of more than 5 tons. Vehicles of categories M2 and M3, in turn, according to the arrangement of passengers are classified into: **Class I.** Vehicles built with areas for standing passengers allowing frequent movement of these. **Class II.** Vehicles built mainly for the carriage of seated passengers and, also designed to allow the carriage of passengers standing in the passageway and/or in an area that does not exceed the space provided for two double seats. **Class III.** Vehicles built exclusively for the carriage of seated passengers.(INEN, 2012)

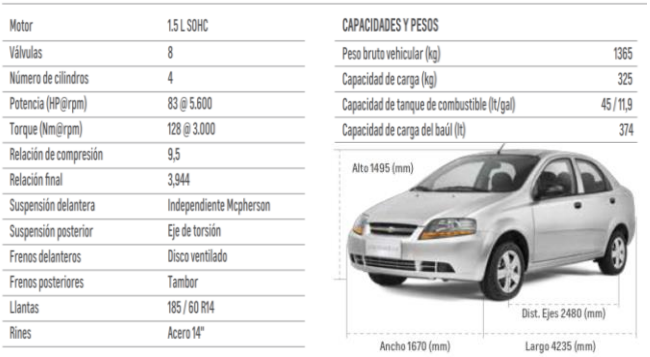

Figure 1:Data Sheet Chevrolet Aveo Family

Road selection

For the relevant tests, the type of roadway is selected, according to the regulation it must be completely flat with an inclination of ±1o. The coefficient of friction should be good preferably asphalt, unless it is another type of test that requires different types of roadway.(Oficial et al., 2016)

TABLE 1: ROAD CHARACTERISTICS

Location	Dimensions		Type of Road	Slope
	Long	Width		
Ecuador, Chimborazo, Riobamba	1600 m	29 m	Floor	± 12 %

Source: Authors

Brake pickup selection

According to (Arms 2017, p. 27) it should be noted that the maximum temperature for the coating material to start to crystallize is 300oF equivalent to approximately 150ºCDuring the 1990s, a new trend emerged in the development programmes of major vehicle manufacturers and friction materials in order to replace the heavy métal contents of the friction material (antimony

trisulfide, lead or galena sulfide, molybdenum disulfide, copper fibres and copper components as well as silicon fibres) with non-toxic compounds , in order to avoid the negative impact of such materials on the environment and humans. It works on an organic material that does not disintegrate at high braking temperatures and maintains its friction characteristics in a wide temperature range. A material that supports wear without damaging the other surfaces. We are facing the emergence of a new generation of friction materials of superior performance and more environmentally friendly, as well as with the people who are in contact with these materials every day.(Frenado, n.d.).

Bosch organic composition pill

Undergone a lot of stress:

Brakes Brakes have to withstand extreme stress: braking work is approximately ten times the propulsion power, which causes the pickups to heat up a lot. For example, after long descents on mountain roads, or when driving on motorways with intermittent stops due to a hold, they reach temperatures between 600 and 650 oC. At certain points the temperature can rise even to several thousand degrees Celsius. Therefore, to be safe, it is advisable to periodically check the brake pads and replace them only with quality products, such as Bosch brake pads.

Figure 2 Bbosh ceramic pills

Source: https://apcherramientas.com/producto/pastillas-de-freno/

Semi-metal premium pill

Made in Colombia by autoparts imfrisa, it offers safety, a high coefficient of friction of class FF with 0.402 in cold and 0.363 hot, allowing a quick response of the driver applying less effort. Complies with the NTE INEN 2185 regarding the coating of the brake pads.

Figure 3 Semi-metallic composition pill

Souce: https://www.imfrisa.com.ec/productos/frenos-y-friccion/

Ceramic Litton Pickup Litton

Manufacturers of brake pads, in terms of research and development aim to meet the needs of users, offering safety, comfort, efficient braking, very low wear and friendly with the brake disc

Figure 4 Litton ceramic composition pills

Souse: http://littonpads.com/productos/

Testing and data collection

General considerations

The following considerations must be taken into account in order to carry out the test in accordance with ECE 13 – H: - The tyres must be cold and have the pressure prescribed by the manufacturer and the braking process will be given without locking the wheels, without the car being defevered from a road width of 3.5 m and the yaw angle no more than 15o.(Oficial et al., 2016). There are 2 types of tests for calculating the efficiency of the service brake system, using the braking distance, for this study the most suitable is the type 0 test detailed below:

Test Type 0

Conducting the type 0 test of the ECE regulation 13 – H must be carried out under the following conditions:

- The initial average temperature on the service brake linings must be in the range of 65oC to 100oC.(Oficial et al., 2016)

- The distribution of the mass on each axle shall be that declared by the vehicle manufacturer.(Oficial et al., 2016)

- The test must be repeated at least five times with the vehicle unloaded, in addition to the driver there can only be one person for the handling of measuring equipment and instruments.(Oficial et al., 2016)

- The brake discs must be cooled for each test until the initial temperature is set.(Oficial et al., 2016)

The Type 0 test can be developed in two ways, with the engine clutched and with the engine disseed, the characteristics of each are shown below:

TABLE 2: WAYS TO PERFORM THE TYPE 0 TEST

Motor desembragado	v	100 km/h.
	s ≤	$0,1v + 0,0060^2$ (m)
	dm ≥	6,43 m/s^2
Motor embragado	v	80% Vmáx ≤ 160 km/h
	s ≤	0,1v + 0,0067v2 (m)
	dm ≥	5,76 m/s^2
f		6,5 - 50 daN

Souse: (Oficial et al., 2015)

Being:

v - test speed in km/h

s - braking distance in meters

d_m - medium deceleration stabilized in m/s2.

f - force exerted on the brake pedal in daN

$v_{máx}$ - maximum speed of the vehicle in km/h.(Oficial et al., 2015)

Data collection and processing.

Data collection is a process by which information is obtained and stored, the values obtained in the tests are of numeric type. The data was recorded and its graphical representation was given using the Microsoft Excel 2016 program and Minitab 2018 statistical software.

Data processing and analysis was through descriptive statistics and multiple variable comparison to determine the type of brake pads with better temperature efficiency based on braking distance.

I X Bar Control Chart

The X chart is the representation of the measurements of the samples taken in a process. It is used to establish the lower control and upper control limits of the group X(León Lescano, 2017), for this purpose it would be analyzed based on individual data.

III. RESULTS

The data obtained in carrying out the tests are based on regulation ECE 13 – H. thus the thermal behaviour of the three types of brake pads can be determined according to the braking distance.

Microscopic analysis of brake pads.

Microscopic analysis of the three types of brake pads used in braking tests was performed in the Mechanics Laboratories of Chimborazo Polytechnic High School, using a microscope with the Jeol Eds system, to determine the formulation of each brake pad. This microscope makes it possible to study in situ the structural transformations of the materials.(Reyes Gasga, 2020)

Organic pill

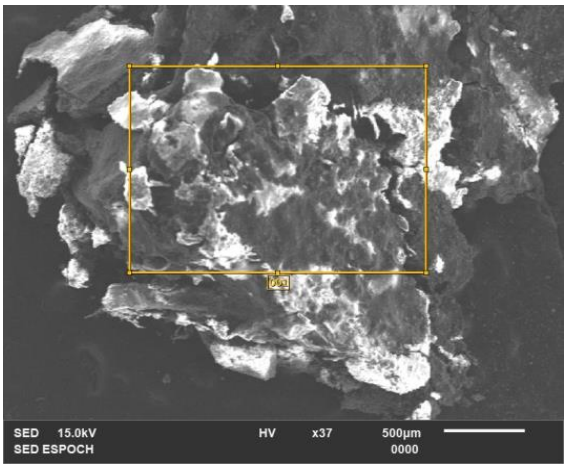

Figure 5 Micrograph - organic pills

Source: Authors

In micrographs made of organic type pickups, the composition of organic brake pads such as carbon, magnesium, aluminum, among other forming materials can be observed, as detailed in Figure 6.

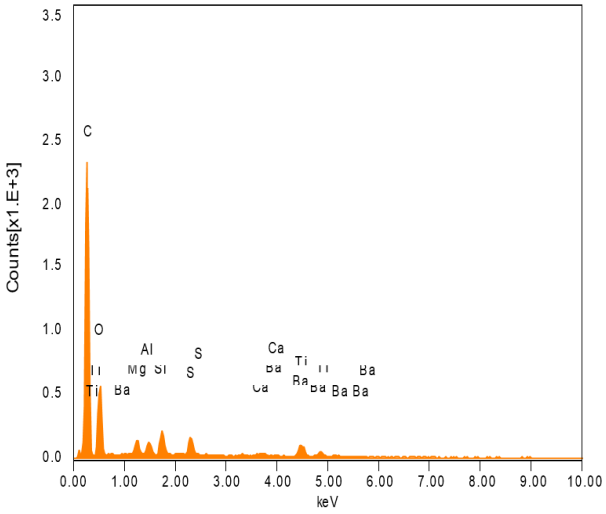

Figure 6 Chemical composition of organic pills

Source: Authors

It is considered an organic type brake pad, due to its high organic matter content such as carbon (C), in its composition there are metals such as barium (Ba), silicon (Si), Magnesium (Mg), among others, which serve to prevent premature wear of the friction material, are also made up of additives such as sulfur.

Semi-metallic pill

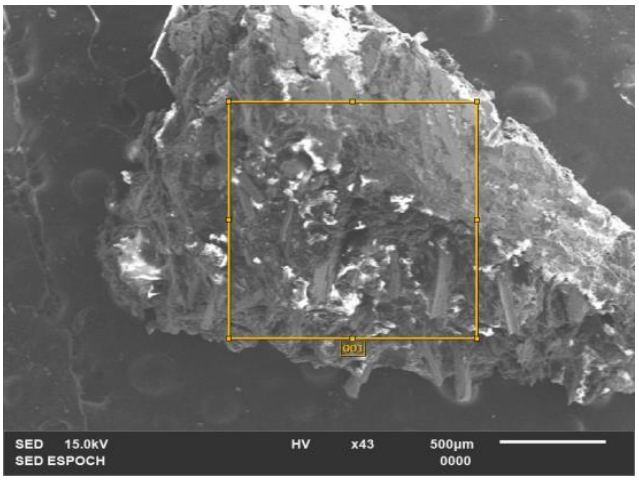

Figure 7 Micrograph - semi-metallic pills

Source: Authors

Micrographing discloses a large percentage of iron (Fe) in its composition, so it is considered a Semimetallic type pill, a lower percentage of carbon (C) is also observed compared to organic type ones.

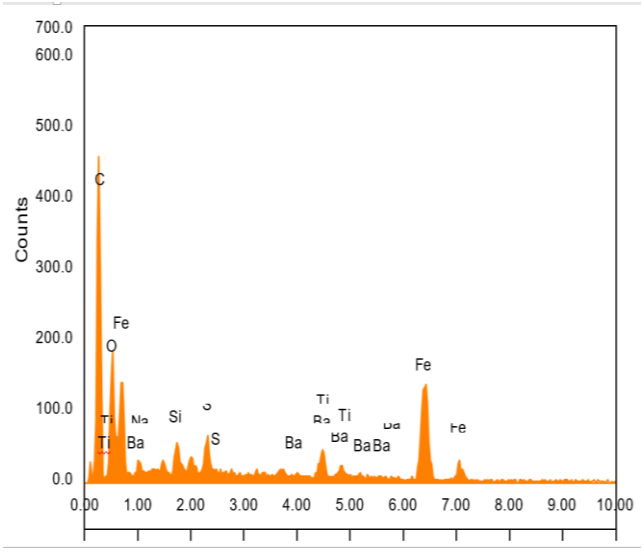

Figure 8 Chemical composition of semi-metallic pills

Source: Authors

Ceramic pill

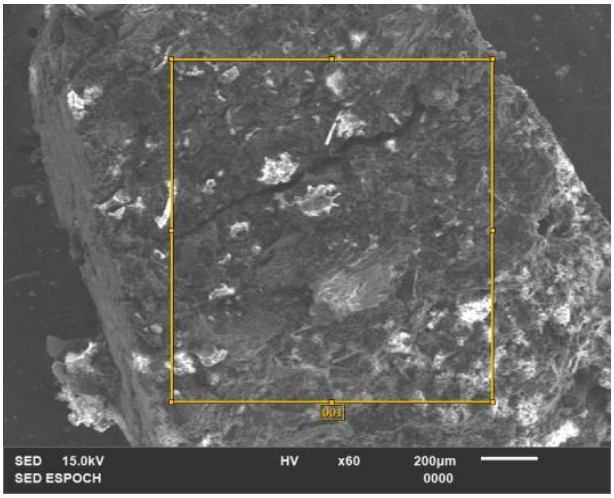

Figure 9 Micrograph - ceramic pickups

Source: Authors

In micrograph made to ceramic type brake pads a high carbon content (C) is observed, in addition the composition of silicon (Si) and Magnesium (Mg) are higher compared to the previous two types of pads.

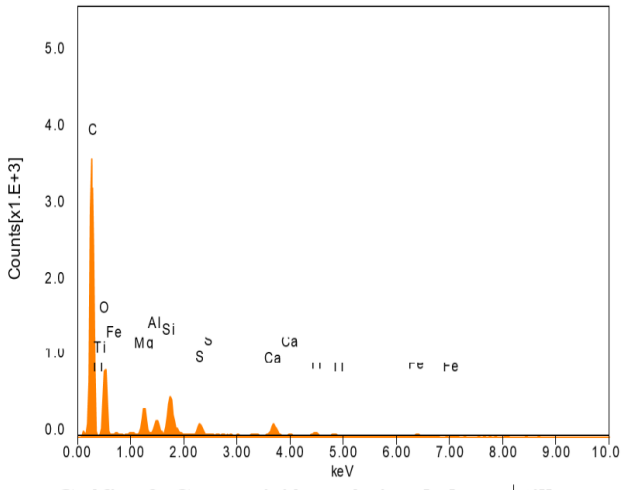

Figure 10 Chemical composition of organic pills

Source: Authors

Execution of the test at 100 km/h

When the conditions for testing have been verified, the vehicle has been carried out at a speed of 100 km/h, when the speed is reached, the gearbox is placed in a neutral position and the braking distance data is carried out by taking the braking distance data using a tape measure and the maximum braking temperature using the pyrometer, thus obtaining the necessary data.

Data tabulation.

In the tests carried out, the data is taken using the Excel software, alternating the speed between 100 km/h and 50 km/h as indicated by the ECE Standard 13 – H. It is noted that the average deceleration should not be less than 6.43 m/s2

thus, it is guaranteed that the data obtained from the braking distance are within the specifications of the Standard.

Statistical Analysis

Data verification

The individual data obtained in the tests are analyzed by the IM-R control letter, Letters from univariate control for variables apply to quality characteristics that are measured on a numeric scale (X; R; S; Individuals)(RESTREPO Tamayo, 2018), therefore the application of this control letter.

$$s \leq 0{,}1v + 0{,}0060v^2 \text{ m}$$

$$s \leq (0{,}1 * 100) + (0{,}0060 * 100^2) \text{ m}$$

$$s \leq 70 \text{ m}$$

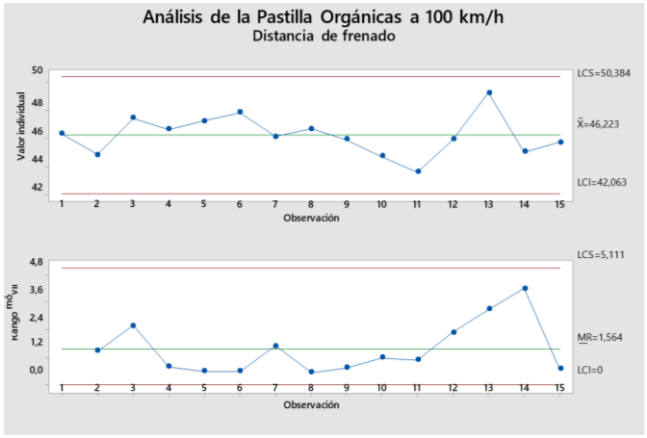

Figure 11 Chemical composition of organic pills

Source: Authors

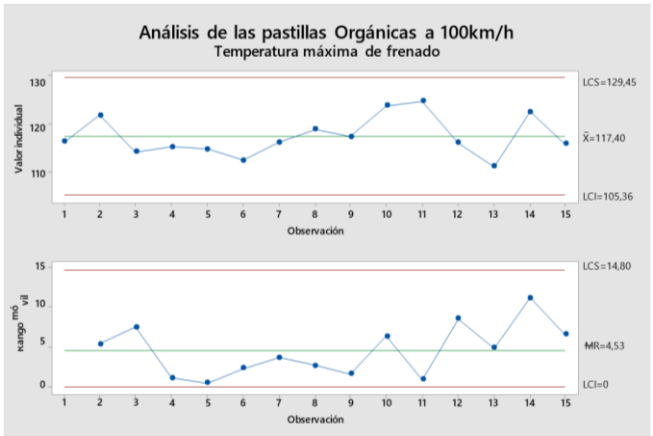

Figure 12 Temperature of brake pads

Source: Authors

Figures 11 and 12 show the analysis of the data for the organic type pickup, an average of 46.22 m is obtained for the braking distance this being the control limit; complying with the 70 m specification limit required in ECE 13 – H. Temperature data is also validated because it is within the control limits.

Variance analysis

To determine which pickup provides greater braking efficiency based on temperature variance analysis (ADEVA) is used in Infostat software, to determine if there is a significant difference between treatments. To determine which pair of means are different the multiple comparison test is used, in the case of this investigation the Duncan Test is used, for the testing of hypotheses. The analysis for the various treatments at a speed of 100 km/h is detailed below.

Braking Distance

TABLE 3: TOTAL SAMPLES

Variable	N	R^2	R^2 Aj	CV
Braking Distance	45	0,78	0,77	3,78

Source: Authors

TABLE 4: ANALYSIS OF VARIANCE (SC TIPE III)

F.V	**SC**	**gl**	**F**	**p-value**
Model	545,63	2	73,59	<0,0001
Treatment	545,63	2	73,59	<0,0001
Error	155,63	42		
Total	701,32	44		

Source: Authors

Test: Duncan; Alfa=0,05; Error: 0,3,7070; gl: 42

TABLE 5: DUNCAN TEST FOR STOPPING DISTANCE

Treatment	**Measures**	**n**	**E.E.**			
Organic	46,22	15	0,50	A		
Semi-metallic	54,57	15	0,50		C	
Ceramics	51,90	15	0,50		B	

Source: Authors

Maximun Braking Temperature

TABLE 6: TOTAL SAMPLES

Variable	N	R^2	R^2 Aj	CV
Braking Distance	45	0,78	0,77	2,96

Source: Authors

TABLE 7: ANALYSIS OF VARIANCE TABLE (SC TYPE III)

F.V	**SC**	**gl**	**F**	**p-value**
Model	2083,26	2	74,6	<0,0001
Treatment	2083,26	2	74,6	<0,0001
Error	586,44	42		
Total	2669,70	42		

Source: Authors

Test: Duncan; Alfa=0,05; Error: 13,9628; gl: 42

TABLE 8: DUNCAN TEST FOR MAXIMUM BRAKING TEMPERATURE

Treatment	**Measures**	**n**	**E.E.**			
Organic	117,40	15	0,96	A		
Semi-metallic	133,93	15	0,96			C
Ceramics	127,56	15	0,96		B	

Source: Authors

According to Duncan's test, the letters are defined

According to the means from lowest to highest, in addition, the means with a common letter are not significantly different (p> 0.05).

Below, graph 10-3 with an initial braking speed of 100 km / h shows the temperature averages as a function of the braking distances of the different types of brake pads:

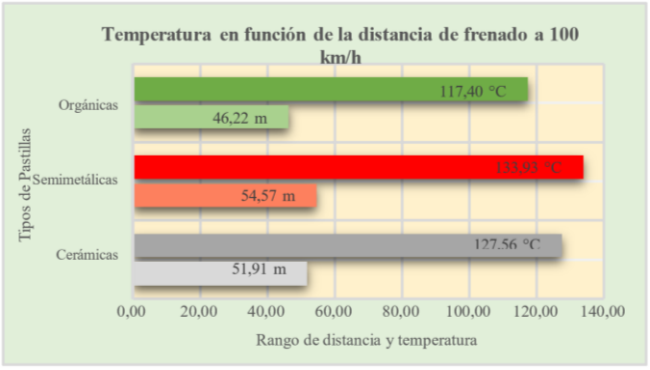

Figure 13 Test result at 100 km/h

Source: Authors

Development of trials at 50 km/h

Figure 14 Braking distance at 50 km/h

Source: Authors

DATA TABULATION

The data collection was carried out in a similar way to the previous tests, as indicated, each test alternates between a speed of 100 km / h and 50 km / h, then to start a new test it is necessary to wait for the initial temperature of braking is in the set range.

STATISTIC ANALYSIS

Data check

An analysis of the data obtained using the IM-R control chart is performed in Minitab software, thus calculating the control limits to determine that the data is reliable.

The specification limit given by the Standard is determined by equation (1) shown below:

$$s \leq 0{,}1v + 0{,}0060v^2 \text{ m}$$

$$s \leq (0{,}1 * 100) + (0{,}0060 * 50^2) \text{ m}$$

$$s \leq 20 \text{ m}$$

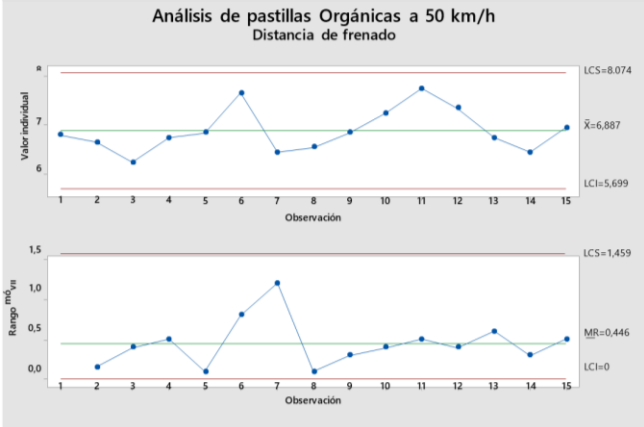

Figure 15 Stopping distance with organic pads

Source: Authors

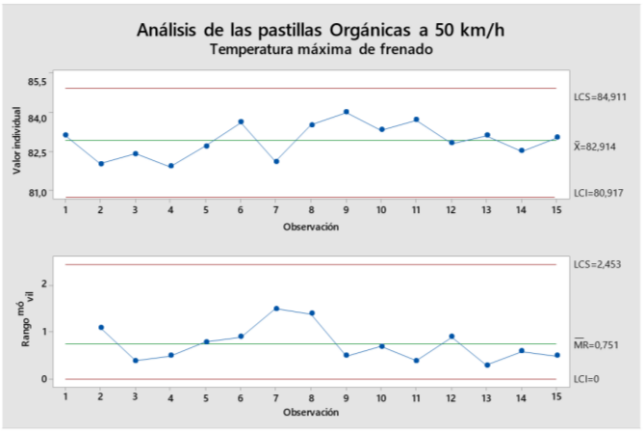

Figure 16 Organic Brake Pad Temperture

Source: Authors

Graphs 14 and 15 show the average braking distance of 6.88 m with a lower control limit of 5.69 m and an upper limit of 8.07 m, these values being within the specific limit given by the 20 m norm. In addition, the mean temperature of 82.91 ° C is within the control limits given by the Minitab software, validating the data collected in the braking tests.

VARIANCE ANALYSIS

Braking Distance

TABLE 9: TOTAL SAMPLES

Variable	N	R^2	R^2 Aj	CV
Braking	45	0,67	0,65	6,55

Distance				

Source: Authors

TABLE 10: ANALYSIS OF VARIANCE TABLE (SC TYPE III)

F.V	**SC**	**gl**	**F**	**p-value**
Model	17,19	2	42,74	<0,0001
Treatment	17,19	2	42,74	<0,0001
Error	8,45	42		
Total			25,64	44

Source: Authors

Test: Duncan; Alfa=0,05; Error: 0,2011; gl: 42

TABLE 11: DUNCAN TEST FOR MAXIMUM BRAKING TEMPERATURE

Treatment	**Measures**	**n**	**E.E.**			
Organic	6,89	15	0,96	A		
Semi-metallic	6,06	15	0,96			C
Ceramics	7,58	15	0,96		B	

Source: Authors

Means with a common letter are not significantly different (p> 0.05),

Maximum Braking Temperature

TABLE 12: TOTAL SAMPLES

Variable	N	R^2	R^2 Aj	CV
Braking Distance	45	0,88	0,87	0,78

Source: Authors

TABLE 13: ANALYSIS OF VARIANCE TABLE (SC TYPE III)

F.V	**SC**	**gl**	**F**	**p-value**
Model	119,65	2	151,45	<0,0001

Treatment	119,65	2	151,45	<0,0001
Error	16,59	42		
Total	136,24	44		

Source: Authors

Test: Duncan Alfa = 0,05; Error: 0,3950; gl: 42

TABLE 14: DUNCAN TEST FOR MAXIMUM BRAKING TEMPERATURE

Treatment	**Measures**	**n**	**E.E.**			
Organic	82,91	15	0,16			C
Semi-metallic	80,95	15	0,16		B	
Ceramics	78,92	15	0,16	A		

Source: Authors

Means with a common letter are not significantly different (p> 0.05)

Next, graph 17-3 shows the averages of the temperature as a function of the braking distances of the different types of brake pads:

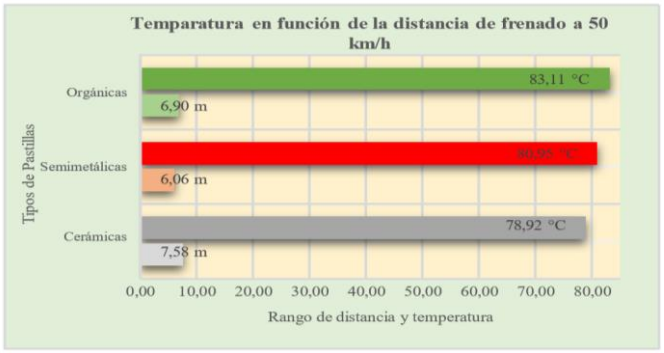

Figure 17 Test result at 50 km/h

Source: Authors

TABLE 15: VARIATION OF TEMPERATURE

Pills Type	**Variation of temperature**

Organic	39,49 ºC
Semi-metallic	52,98 ºC
Ceramic	48,64 ºC

Source: Authors

III. DISCUSSION

It is observed that the braking distance is inversely proportional to the maximum braking temperature. In other words, the greater the braking distance, the lower the maximum braking temperature.

According to the means established in table 24-3 obtained from ADEVA, the brake pads will be evaluated at an initial braking speed of 50 km / h and 100 km / h, to determine which has a good thermal behavior according to the braking distance and thus, opt for the type of brake pad with better performance.

The organic type pads at 50 km / h, offer a regular braking distance of 6.89 m with a bad maximum temperature of 82.91 ° C; at 100 km / h the braking distance is good of 46.22m with an equally good maximum temperature of 117.40 ° C, with a temperature variation of 34.49 ° C.

The semi-metallic type pads at 50 km / h, offer a good stopping distance of 6.06 m with a regular maximum temperature of 80.95 ° C; at 100 km / h the braking distance is bad of 54.57 m with an equally bad maximum temperature of 133.33 ° C, with a temperature variation of 52.98 ° C.

The ceramic type pads at 50 km / h, offer a bad stopping distance of 7.58 m with a good maximum temperature of 78.92 ° C; At 100 km / h the braking distance is regular 51.91m with a maximum temperature that varies slowly from 127.56 ° C, its thermal variation is 48.64 ° C.

To ensure that it does not reach critical temperatures and tend to crystallize, thus losing the coefficient of having the lowest temperature variation of 34.49 ° C, but due to its various disadvantages, its selection is ruled out, thus selecting; the ceramic type pad that has a temperature variation of 48.64 ° C offering better performance.

IV. CONCLUSIONS

The micrograph made of a sample of the different treatments affirms that they have a different chemical composition, allowing the experiment to proceed based on international standards.

In the statistical analysis, the values obtained by coupling the pyrometer do not exceed the control limits, likewise, the braking distance data does not exceed the control and specification limits, being the specification limits for the case of 100 km 70m / h of 70m and in the case of 50 km / h of 20m, the data is validated using the I-MR individual data control chart in the Minitab software, thus deducing that the organic, semi-metallic and ceramic tablets comply with the standards of Regulation ECE 13 - H.

By means of the multiple comparison test of Duncan's Test, it is verified that the three treatments are significantly different, obtaining a probability $\leq 0.001\%$ for the approval of the null hypothesis (H0); thus affirming, the alternative hypothesis (H1), to determine which treatment offers an optimal temperature as a function of an efficient braking distance, the values of the means of the three treatments obtained by ADEVA are compared, these data being reliable and validating the study.

After the tests and analysis, it is determined that the organic type pads offer good performance in terms of braking temperature with a minimum variation of 34.49 ° C. but discarding its usefulness due to its various disadvantages, thus selecting the ceramic type tablet that has a variation in temperature of 48.64 ° C, in this way it is ensured that the tablets do not crystallize and

guarantee the safety of the occupants of the car. vehicle.

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