

Friction-related Efficiency in Hydrogen-powered DC-controlled Cars

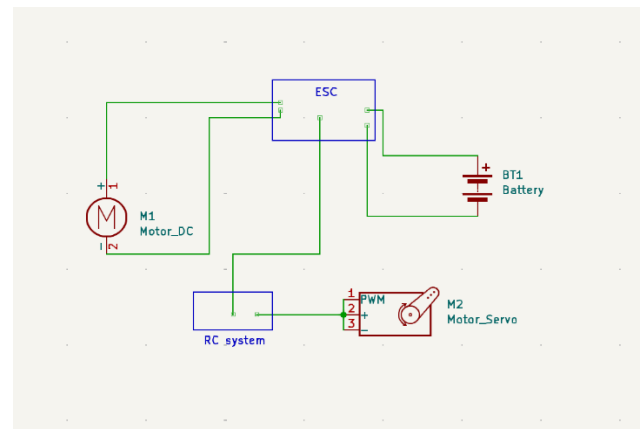
Ceylin Melek Asil, Fatma Altun, Birgül Çelikler Sarıahmet
Hisar School
Istanbul, Turkey

Abstract - In response to the problems caused by fossil fuels around the world, hydrogen energy, which is part of renewable energy, provides extra sustainability in its use in cars. Although it is connected to a battery like electric vehicles, this car, which also derives a large part of its energy from hydrogen, i.e., water, offers an opportunity for future car designs. The car kit belongs to a competition offered by H2 Grand Prix, and our task as a group is to create innovation through this kit that will enhance the use of the car. In the experiment that will be performed, the car will be examined on three surfaces with different coefficients of friction that are guessed to affect the vehicle's speed and energy consumption. The purpose of this article is to describe this process and examine the friction factors in DC vehicles independently of hydrogen energy.

Key words: Hydrogen energy, friction factor, DC cars, renewable energy, sustainability, rolling without slipping motion

I. INTRODUCTION (Set Up)

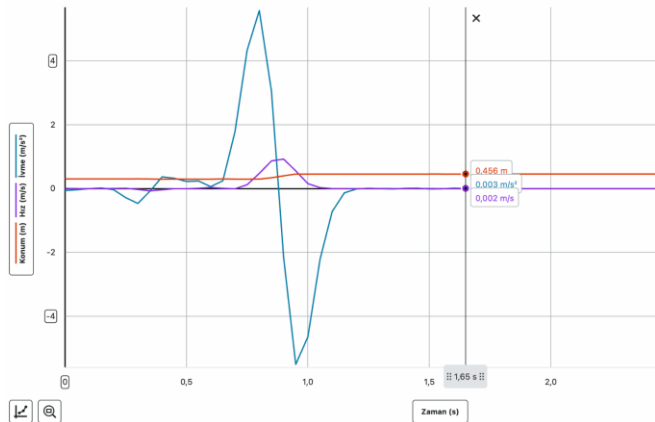
In the setup of the DC car provided for the H2 Grand Prix race, not only physical or electronic mechanisms but also the awareness brought about by the process plays a significant role. Today's rising global temperatures and climate change issues have pushed people to discover consumption methods that cause less damage to nature. In this quest, it is crucial to offer such competitions so that new generations can actively follow the process. In this way, individuals have the opportunity to work on a DC car while gaining a positive awareness for a sustainable world. The competition categories feature different kit models based on age and experience. The kit used in the experiment mentioned in the article is the top-tier "Pro" model. This model involves more teamwork for setup and development and requires extra effort. (1)



Drawn schematic is the simple description of the electronic connections inside the DC car, these connections are also thought throughout the process with lessons to the team. The schematic shows the 7.2V battery used by the system connected to the Electronic Stability control device also known as the ESC which is a key element of the system. RC system enables the connection with the remote control where it is responsible for servo and the motor. The RC system plays 2 different roles in the remote. (2)

First is the servo's control which is connected to the front right wheel of the car and the movement of the car. Servos connection is a mechanic process which needs very detailed work for the wheels to be facing perfectly to the front (not right or left). This is a key organization since the wheels are the main element that affects the friction.

Second is the motor's velocity. The remote control is able to set fixed rates to factors such as End point, exponential, dual rate etc. which sets more standardized testing between the surfaces as these values will be kept constant. In addition, tests will be done in full speed (which is minimized by the controller to get accurate results) in order to prevent the differences that might be caused by the driver's hand giving different speed values to the car which must be avoided to perform the experiment.



Provided graphs are some example samples of how experimental data was collected using a motion sensor to measure mainly the acceleration using vernier graphical analysis. Graph 1 shows a simulation done by driving the mini hydrogen car on tile surface, while the data collected on Graph 2 was when the car was on a rug, (place to provide a higher friction coefficient). Lastly, the third surface was an epoxy surface with a vinyl flooring. This information was done by getting the site where the surfaces were purchased from as a basis. (6) Rest of the data set with the maximum acceleration points.


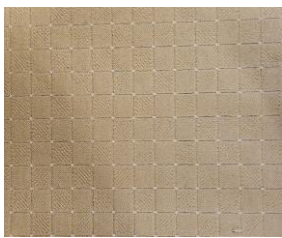
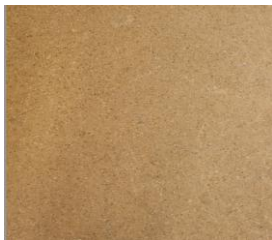
Trial 13:	2.78	8.36	1.669
Trial 14:	3.724	7.38	1.357
Trial 15:	3.576	11.26	1.193

15 trials were made	Experiment al - raw data:	(Acceleration (m/s ²)) - maximum	Graph 2
	Tile	Rug	Epoxy - vinyl flooring
Trial 1:	4.791	12.601	9.347
Trial 2:	5.101	12.387	10.479
Trial 3:	4.041	11.323	9.002
Trial 4:	4.290	12.323	9.036
Trial 5:	4.431	10.917	8.524
Trial 6:	3.907	10.098	8.448
Trial 7:	3.585	11.375	9.280
Trial 8:	4.035	11.436	8.920
Trial 9:	3.285	12.160	7.980
Trial 10:	3.899	11.442	8.552
Trial 11:	4.410	10.354	8.753
Trial 12:	4.643	11.127	9.338
Trial 13:	4.245	10.824	9.114
Trial 14:	5.580	9.730	8.571
Trial 15:	4.991	14.212	9.081

15 trials were made	Experimental - raw data:	(Acceleration (m/s ²)) - average	Graph 1
	Tile	Rug	Epoxy - vinyl flooring
Trial 1:	3.48	10.296	1.24
Trial 2:	3.192	8.908	2.189
Trial 3:	2.912	8.056	1.988
Trial 4:	3.096	8.868	1.139
Trial 5:	3.076	7.976	1.447
Trial 6:	2.888	8.224	1.444
Trial 7:	2.62	8.764	1.552
Trial 8:	3.116	8.632	1.852
Trial 9:	2.424	8.22	1.316
Trial 10:	2.892	8.16	1.614
Trial 11:	3.18	7.368	1.486
Trial 12:	3.096	8.768	1.643

IV. USING AN AI MODULE TO ANALYZE THE SURFACES

Surfaces chosen:

Tile	
Rug	
Epoxy - vinyl flooring	

1) Tile (Stone/Ceramic Composite)

A crystalline like structure is formed via using sand, clay and feldspar. By forming an homogenous compound and compression technique the tile surface is obtained. Smooth tiles lie between 0.40-0.50 on their coefficient of friction. From this data it can be concluded that a smooth tile type has been used, more likely a glossy smooth surface. Even if there are many tile types, it is mostly known that the coefficient of static friction depends on the material and the roughness itself too. Therefore, it is also very important to understand the difference between presence and absence of wetness/water as well as how it will affect the results. In this example, it has to be clarified that the surface used was dry.(7)

2) Rug (Polypropylene or Nylon Fiber)

Most rugs are made of Olefin or Nylon Polymers textiled on latex surfaces to keep them together. Therefore the roughness of the material must be analyzed in two different surface structures; at the top being a woven carpet with a yarn surface, and where it is woven as at the bottom. (8) Rug surfaces are much thicker and more complex due to yarn structures than tile is. Therefore, They are easily determined to have a greater coefficient of static friction due to their complexity. Rug surfaces are mostly in between 1.00-1.20 friction coefficients. In this example, we are working with a very dense type of carpet with different patterns which might affect the friction coefficient accordingly. Fibers most of the time act like hooks to the materials it is engaging with therefore the structures analysis is also determined by mechanical interlocking too. (9)

3) Epoxy-Vinyl flooring (Polymer Composite)

Epoxy is usually a "sandwich" like structure with PVC, also known as polyvinyl chloride, plasticizers and an Epoxy resin at the top. These floor structures are more similar to plastic and not as "stone like" as tile surfaces. These surfaces are mostly used to make up a "softer" surface in the used areas. It is also known that even if this is not just limited to vinyl flooring itself, when different flooring types are compared the surfaces covered with this flooring type decrease friction values due to its very smooth structure even on tile (vinyl work like a "cover" on to the floor itself). (10) Since in this example we are working with an epoxy floor which is a polymer, the structure will be flat on the molecular level too. (11) From these examinations, it is thought that this floor type's static friction coefficient will be way lower down to 0.75 to 0.90.

V. MORE DATA AND INFORMATION ABOUT THE EXPERIMENT

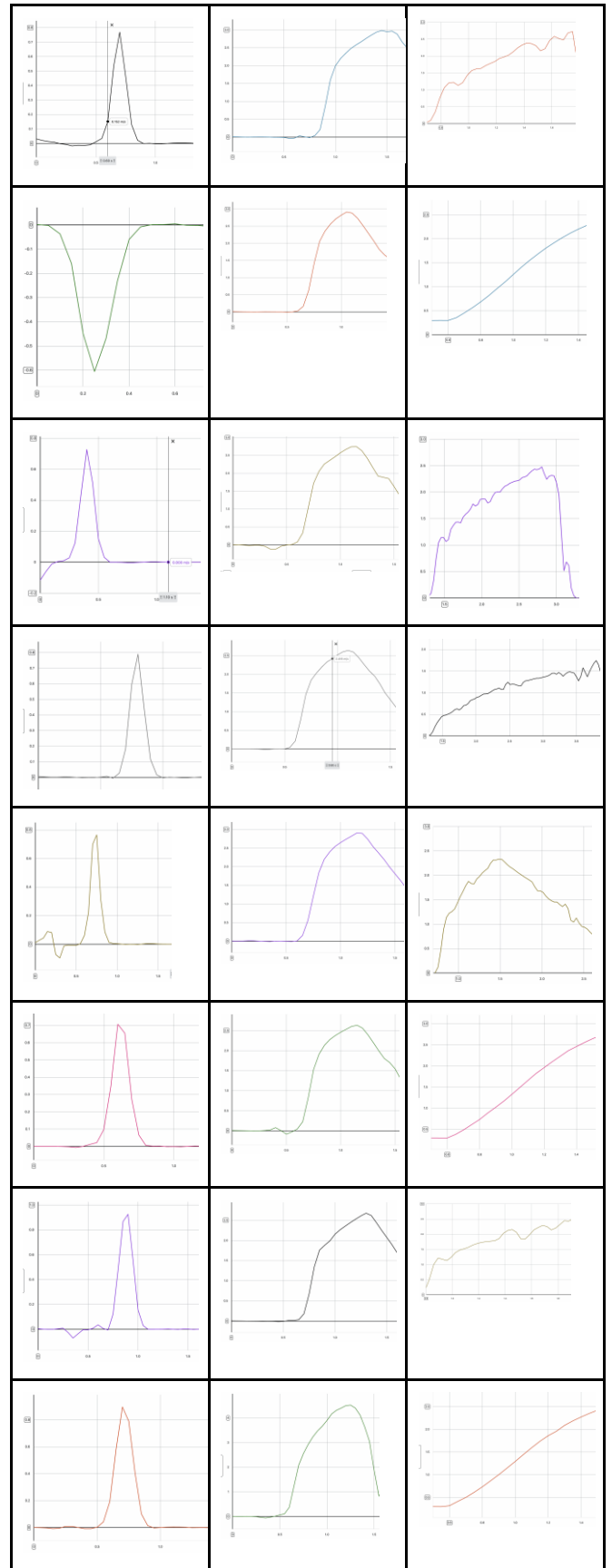
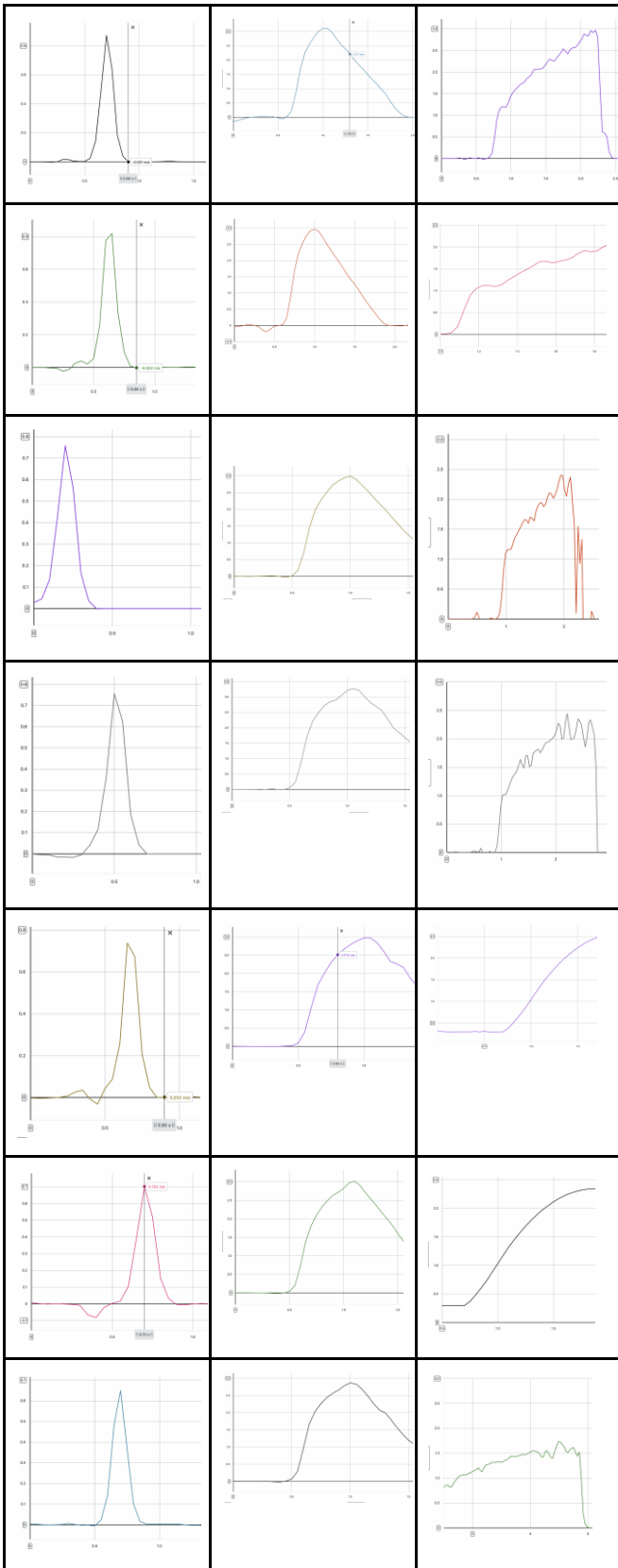
All Data Set:

measured velocity graphs m/s to s: used to find the acceleration

X-axis: time (s)

Y-axis: velocity (m/s)

Data set 1 - measured on tile surface	Data set 2 - measured on rug surface	Data set 3 - measured on epoxy surface
---	--	--



VI. EVALUATION

As it is seen from the table too, there is a drastic difference between the low and high friction coefficient sets. On the other hand, data shows a positive correlation between the acceleration, and the coefficient of friction. Therefore, this test has been useful to see the different outcomes from the thought hypothesis. Even if the provided calculations and equations are true, something more fascinating took place and showed the daily usage of car wheel designs. This gave off an outcome that the friction between the surfaces of the floor and car is designed to help the forward movement of the car.

In the experiment, “Rolling without skidding” motion examination was approved and the differences of accelerations is seen to be due to translational motion of the car. Increasing the static friction by a lot uses too much energy on the rolling motion, limiting translational motion that is related to the forward acceleration of the car. Another factor that might be affecting the results between different surfaces is that this situation demonstrates how the “turning” motion of the wheels contributes to the forward force. The friction factor involved in a rotating object plays a role in enabling that turning motion. This allows the car to continue moving without skidding. This time, if the static friction factor is reduced too much, changing the coefficient of friction, the vehicle automatically struggles to perform the same rotation, increasing the likelihood of skidding. Skidding is a problematic situation since it causes a total loss of traction of the car. (12) For this reason, although friction is thought to hinder forward movement, when friction occurring in interaction with the ground is considered, it contributes to spinning movement. (13) Wheel designs have also been modified in this way because, instead of a smooth wheel, a material that grips the ground better is preferred.

When examining the graphs, the slowing down of acceleration as friction decreases is related to the wheels losing traction. Therefore, more force will be required to achieve the same acceleration or speed in the same amount of time. This situation leads to unnecessary energy loss. In a competition focused on energy conservation, where the use of hydrogen fuel cells is limited, choosing smoother wheels would be a poor choice as it would prevent traction. The reason for this is the desire to achieve greater efficiency with less distance traveled in order to save energy, and the primary force used to achieve this desire comes from the wheel and the rotational movement.

Surface	Mean a (max) (m/s ²)	Median a (max) (m/s ²)
Tile	4.331	4.290
Rug	11.487	11.375
Epoxy-Vinyl	8.970	8.920

When the values provided by the data are calculated statistically, it is seen that the mean and median provided by the acceleration yield higher values on surfaces with high friction. Contributing to the analysis reached in these statistical calculations, this explains why the wheels are designed to support forward movement.

Comparing the coefficient of friction:

In order to calculate the coefficient of static friction; we must use the torque formula assuming rotational inertia of a wheel is MR^2 .

We can start our calculations with the main rotational motion formula which is:

$$\tau = I\alpha = F_f \cdot R$$

And as linear acceleration is written as the rotational acceleration multiplied by R, the radius of the wheels cancels out when inertia is also put to the formula. Therefore the equation will come down to:

$$F_f = \frac{(mR^2) \cdot a}{R^2}$$

$$F_f = ma$$

From here we must move to the static friction's regular formula where normal force can be concluded as the weight since the surfaces used are all plain and they don't have a value of angle to separate up the normal force. This formula given is only true for the maximum value of static friction as static friction is not a perfectly constant value. To find the maximum value, we need to observe the moment where the

friction transforms from static to kinetic, and this transformation moment will occur as the car slips after a while because of kinetic friction. The reason why maximum acceleration was used instead of the average is because the experiment wants to observe this moment where the static friction will be at its maximum as well.

As:

$$F_f = \mu \cdot F_N = \mu mg$$

When masses are also canceled out, the coefficient of static friction can be found by simply dividing the maximum acceleration by the gravitational constant ($g=9.81$).

General formula used:

$$\mu_s = \frac{a_{max}}{g}$$

Tile:

$$\mu_s = \frac{4.331}{9.8} \approx 0.442$$

Rug:

$$\mu_s = \frac{11.487}{9.8} \approx 1.172$$

Epoxy:

$$\mu_s = \frac{8.970}{9.8} \approx 0.915$$

By the found different coefficients of frictions it is possible to say a direct relationship is observed between the maximum acceleration of the car and the friction that is affecting the rotational motion of the wheels. This was caused because of the mechanical energy usage of the car divided into linear and rotational as talked about before.

VII. CONCLUSIONS

As a result, the hypothesis is proved to be right since it is seen that a higher coefficient of friction is leading to a higher average acceleration value too. By this, it has been observed that when friction with the ground is reduced excessively, the wheels cannot grip the ground sufficiently, leading to a risk of skidding as well as the highly use of rotational energy causing less translational movement to occur. The experiment has been effective in examining the

nature of rotational motion and its connection to physics. Based on the results, it was decided not to make any changes to reduce surface friction, and innovative wheel designs are also supported in this context.

The correlation between excessive friction and excessive acceleration is a ground-related issue. Nevertheless, it is thought that reducing friction beyond the wheel-surface relationship for example in the motor system will also reduce energy loss in terms of formulas. This idea has also opened up another research topic, enabling a new experiment.

REFERENCES

- [1] Via Aurea, s.r.o., "H2 Grand Prix homepage," h2grandprix.com, 2025. [Online]. Available: www.h2grandprix.com. [Accessed: Jan. 2026].
- [2] D. Claes, et al., "Development of an autonomous RC-car," in *Int. Conf. on Intelligent Robotics and Applications*, Berlin, Heidelberg: Springer Berlin Heidelberg, 2013.
- [3] J. Y. Park and M. Salmeron, "Fundamental aspects of energy dissipation in friction," *Chem. Rev.*, vol. 114, no. 1, pp. 677-711, 2014.
- [4] B. Sorensen and G. Spazzafumo, *Hydrogen and fuel cells: emerging technologies and applications*. Elsevier, 2018.
- [5] Y. Wang, et al., "PEM fuel cell and electrolysis cell technologies and hydrogen infrastructure development—a review," *Energy Environ. Sci.*, vol. 15, no. 6, pp. 2288-2328, 2022.
- [6] Gerflor, "Gerflor - zemin çözüm merkezi | Gerflor professionnels," gerflor.com.tr, 2025. [Online]. Available: www.gerflor.com.tr. [Accessed: Mar. 31, 2026].
- [7] "Coefficients of static and dynamic friction of ceramic floor tiles: proposal of new method of surface roughness determination," *Int. J. Metrology Quality Eng. (IJMQE)*, 2019. [Online]. Available: www.metrology-journal.org. [Accessed: Apr. 2026].
- [8] H. Ikuko and T. Gunji, "Slipperiness and coefficient of friction on the carpets," *J. Textile Eng.*, vol. 47, no. 2, pp. 53-58, 2001.
- [9] The Carpet and Rug Institute, Inc., "The carpet primer," Dalton, GA, 2020. [Online]. Available: carpet-rug.org. [Accessed: Apr. 2026].
- [10] Solution Engineering, "Industrial flooring," 2018. [Online]. Available: solutionengineering.com. [Accessed: Apr. 2026].
- [11] JD Flooring Ltd., "The durability of epoxy resin garage floors explained," jdflooringltd.co.uk. [Online]. Available: www.jdflooringltd.co.uk. [Accessed: Apr. 8, 2026].
- [12] A. L. Candy, "Elimination of skidding due to steering mechanism on motor cars," *Amer. Math. Monthly*, vol. 27, no. 6, pp. 245-252, 1920.
- [13] Z. Farkas, et al., "Frictional coupling between sliding and spinning motion," *Phys. Rev. Lett.*, vol. 90, no. 24, p. 248302, 2003.
- [14] Gemini 1.5 Pro, "Analysis of tile, rug, and epoxy-vinyl flooring surface structures and friction coefficients," Google, Apr. 18, 2026. [Online]. Available: gemini.google.com.