THEORETICAL AND EXPERIMENTAL CHARACTERIZATION OF HANDLING OF LOADS AN AUTOMATED SYSTEM USING VACUUM TECHNOLOGY

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Abstract: *The two most common techniques used for fixation and of parts and materials in the industry are mechanical clutches and pneumatic suction cups. These have different characteristics, but generally perform the same function with respect to the displacement of material. The suction cups are noted for being great elasticity, being the best choice when the goal is to arrest or transport brittle materials, for example glass. The purpose of this work is to carry out some tests for lifting ideal parameters for the selection of the handling system loads by using a vacuum suction technology, automotive intended for industrial processes. In these assays will be evaluated first five physical aspects: the optional suction cup material, the air pressure system, roughness and weight of the materials to be handled and the level of vacuum generated by the system. In this work a data acquisition board will be implemented with the integration of the PIC microcontroller family, which will receive information via an analog signal from the pressure transducer, and make it available in an LCD display in order to pressure the system monitor.*

Keywords: *Handling System Loads, Suction Cups, Vacuum and Roughness.*

1. Introduction

Currently the handling loads systems are indispensable in automated processes, because they provide the more flexibility and greater productivity. One of the techniques used in the industry is the materials handling by suction cups, which have the characteristic of not damaging the parts to be handled. This important characteristic for materials fragile, such as glass, by requires specific care and handling of them. Although tough and rugged, the glass is also a brittle material and may break altogether from a simple crack in one of its surfaces. For this reason, advanced technologies of control and manipulation are essential to prevent falls and impacts during transport.

In any industrial process, operating conditions are subject to variation over time, the level of liquid in a tank, the pressure in a vessel, the flow of a fluid, all of these conditions can vary. Currently there is a wide variety of equipment to help in the control and monitoring of processes, which together may constitute chains control single or multiple, adapted to numerous control problems and a large number of types of processes [1].

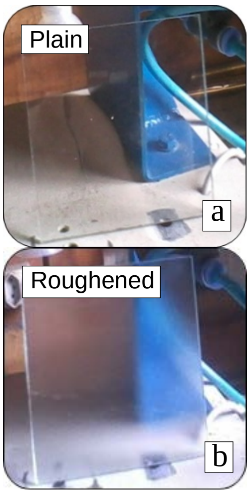
One of the parameters that directly contribute the behavior of handlers for suckers is the roughness of the parts. It plays an important role in mechanical components behavior and consisting of the set of irregularities, that is, small protrusions and recesses which characterize the surface, influencing the quality of slippage, wear resistance, surface resistance offered by the flow of fluids and lubricants, quality of grip that the structure offers the protective layers, corrosion resistance and also on the seal [2].

In this work we will use two parameters for measuring roughness, R_a and R_z, as they are the most widespread due to its simplicity in processing surface roughness tester and also by the type of process requirement, as in the case of the suction cups. The parameter R_a is the most well-known, accepted and used worldwide, is used in virtually all manufacturing processes and all conventional measuring equipment texture (surface roughness tester) has it as an option [3].

The suction cups, in turn, and to resist large deformations during handling or handling, have several advantages compared to the fastening systems by claws. Among them is the highest speed of operation which increases productivity, ease and quickness in repairs, aspect that reduces downtime for maintenance and low cost of acquisition and installation of components [4].
Select the type of material and size of the cups for an application is essential in any vacuum system. Through calculations of forces involved in the application can determine the optimal size of the suction cup, but the data obtained from these calculations are theoretical and specifications for each application needs results through practical tests [5]. Some parameters should be evaluated for the correct sizing of a sucker as mass, force, acceleration and friction coefficient. For applications in irregular sheets, defective surface or sudden movements, it is interesting to use an additional safety coeficient.
In this context, the article presents some representative for pre-selection of pneumatic components for vacuum technology based on Venturi technique, through the generation of vacuum valves results. This technique consists of passing compressed air through a tube mounted in a bore within which causes a constriction to the flow of air. The air flowing through the tubes increases as a function of the flow generated by the restriction orifice. The increase in acceleration of the air flow causes a considerable pressure drop in the throttling region by causing the action occurs on the suction cups.

2. Experimental Development

For the tests, two bodies of evidence were selected as shown in Fig.1. The glass like material was chosen because of relying on specific precautions for handling and transport, creating the need to make the system as reliable as possible manipulation. Both specimens have the same dimensions, these being 95 x 95 mm by 3 mm thick and weigh 0.120 kg respectively. Due to the low weight provided by the specimens for the tests, were added the same steel splints to meet the load requirement. After the selection of specimens, roughness measurements were performed through a surface roughness tester, selecting parameters and filter suited for the surfaces. In order to avoid measurement errors caused by the influence of external events such as dirt or imperfections of the material itself, the specimen was previously washed with chain water and subsequently cleaned with ethanol before each measurement. To provide greater security to the study, three tests each parameter of roughness (R_a and R_z) were performed at three different locations each specimen twelve tests were performed.



Specimen (a)	R_{a} (μm)	R_{z} (μm)
Measure 1	0,01	0,20
Measure 2	0,01	0,20
Measure 3	0,01	0,10
Average	0,01	0,17
Standard deviation	0,00	0,06

Specimen (b)	R_{a} (μm)	R_{z} (μm)
Measure 1	11,57	49,81
Measure 2	13,51	51,92
Measure 3	13,41	51,97
Average	12,83	51,23
Standard deviation	1,09	1,23

Fig.1. Specimens: (a) plain glass (b) roughened glass and measurement of surface roughness

To study the characterization of surfaces that influence the efficiency of the vacuum process was developed a prototype for the LASPHI simulating the actual working conditions of the method of freight transportation. The prototype has a construction with two pneumatic actuators to perform the movements in the X and Y axis, pneumatic valves for the exchange of motion actuators, valve generating vacuum by Venturi principle, a PLC and other safety devices Fig.2 (a). The manipulation method adopted consisted of: vertically move the pneumatic actuator (A) to the specimen, generating a vacuum to keep the specimen caught in the suction, return to the starting point pair then move the pneumatic actuator (B) to the end of full travel with horizontal movement. Then again trigger the actuator (A) and cut the compressed air supply to the generating vacuum valve, releasing the specimen to return the two actuators to its starting point, as shown in Fig.2 (b).

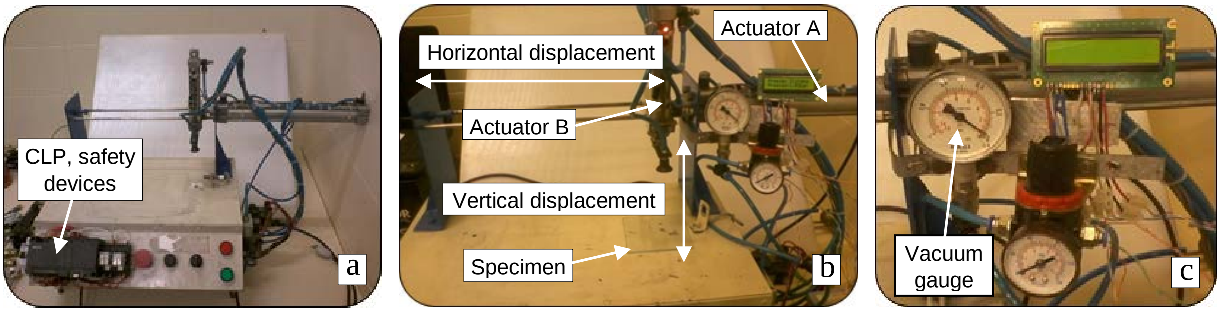


Fig.2. Module tests: (a) prototype for handling and (b) mechatronic devices

Tests conducted on the bench were intended to measure and evaluate some physical parameters necessary for the proper functioning of a vacuum handling system, based on theoretical values mentioned in the course of this work. The following parameters were adopted as optimal labor standards in the tests (Tab. I). In Fig.2 (c) we can also observe that a mechanical vacuum gauge was used for the characterization of the value generated in the vacuum of the suction chamber, indicating the action of 0 to -1 bar, in which it was necessary to collect data manually.

Tab.I. Parameters adopted in the tests

Parameters	Value	Unit.
Operating Pressure	7	bar
Level of vacuum generation valve	70	%
Force lifting of horizontal suction cups	22,4	N
Perfect weight of the specimen (a)	0,708	kg
Perfect weight of the specimen (b)	0,354	kg

In order to the evaluate the best operating condition of the system, some parameters have been purposely altered, such as pressure (4 - 7 bar), the surface of displaced materials (smooth and rough) and the weight of the loads added to specimens (theoretical weight, 100% up).

2.1. Vacuum system applied

In this work the windy flat type and three types of rubber for its design, all with 20 mm diameter were used (Fig.3). These falls into three rubber components: natural: highlights by excellent elasticity and high tensile strength; nitrile: it has huge resistance to oil and oil products and silicone: exceptional resistance to high temperatures.

Fig.3. Model and types of suction cups used

In testing, the generating vacuum valve (Fig. 4) that works by the Venturi principle was used, where the vacuum is generated using compressed air (positive pressure). Below is presented their main characteristics (Tab. II):

Tab. II. Technical data generating vacuum valve

Generating characteristics valve	Value	Unit.
Operating pressure	1 to 10	bar
Operating temperature	-10 to 80	ºC
Vacuum (varies with the inlet pressure)	0 - 660	mmHg
Flow	20	l/min
Venturi orifice diameter	0.7	mm

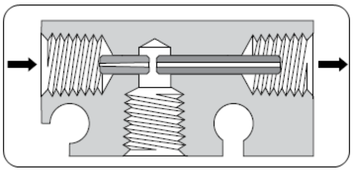


Fig.4. Valve used in the tests.

According to the manufacturer's catalog, this valve operates with 100% vacuum level to a pressure of 10 bar, this means that we have a vacuum level of 70% to our tests, whereas pressure of 7 bar will use as the default. Underscoring that the diameter of the pipe must be dimensioned in relation to the Venturi orifice, which in our case corresponds to a pipe of 4 mm.

2.2. Calculation of the displacement

For the tests was selected valve vacuum that produces 70 % vacuum level at a pressure of 7 bar According to data found in the manual and the suction cup flat type having 20 mm in diameter, was chosen this way the theoretical resultant force will be 22.4 N, according to the manufacturer. The acceleration values were calculated using the values found by measurements carried during preliminary tests with the displacement of pneumatic actuators. To test the effect, was used of stroke cylinder with 270 mm due to the fact make the movements of the worst-case handling system was used for this. These measurements were performed numerous times with the aim of reaching the most reliable possible value. Below the main equation 1 used is presented. In the calculations we used a safety factor 2 to specimen (a) that has the smooth surface characteristic and a safety factor 3 related to the specimen (b) having the characteristic of rough surface, as indicated in the catalog Parker [6].

$$F = m.\left(\frac{g+a}{\mu}\right).s \quad (1)$$

m – Weight [kg]
F – Force lifting [N] – (suction cups in the horizontal position motion)
g – Acceleration of gravity [m/s^2]
a – Acceleration of motion [m/s^2]
s – Safety Factor [---]
μ – Coefficient of friction [0.5] – (empirical value related to the glass, according to FESTO).

Calculating the acceleration of the movement and considering the use of a suction cups 20 mm, is found the weight values for each type of specimen. The specimen (a) and (b), was reached at a value of 0.513 and 0.342 kg respectively.

2.3. Monitoring of air pressure

The system used in the data acquisition process was composed by a Microchip PIC microcontroller family. This system has the function to convert the analog signal from the pressure transducer into a digital signal to be viewed on an LCD screen. In this research the LCD display function was to show in real time the current system pressure as shown in Fig.5 (a) e (b).

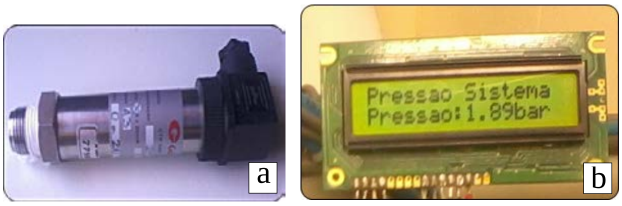


Fig.5. Acquisition of pressure. (a) Pressure transducer and (b) liquid crystal display

Giving emphasis to the pressure control to ensure the manipulation strength and interpretation of pressure data was required to integrate a microcontroller reading. However, as it has not been possible to integrate the microcontroller in the action of some event on the prototype, it was used only to compare the gauge reading of mechanical principle. To read the display in this manner was used RA0 to the analog input of the analog read signal provided by the transducer and the pin (PORT A) necessary for exchanging data eat the LCD screen, as shown in Fig.6 (a).
For reading the analog signal from the pressure transducer whose output signal corresponding to a level of 4-20 mA current four 1K resistors were used in parallel, resulting in a resistance of 250 ohms in series between the power source and thereby generating a voltage drop that will eventually be read and converted to a digital signal by the microcontroller. The microcontroller used in this study is manufactured by Microchip Technology Inc. ® and has the following features: flash memory for instructions (program memory) with 14 bits/word – PIC 16F877A model.
The program was developed in assembly or C programming language [7] and was only restricted in effecting the reading of an external analog signal from a pressure transducer, converts it into a digital signal and make it available on an LCD screen with order to monitor the system pressure. Thus at the beginning of the programming device to the LCD library that is already available to the developer within the development environment for programming and enabled the devices A/D converter is included, allowing the interaction of the two components (Fig.6 b).

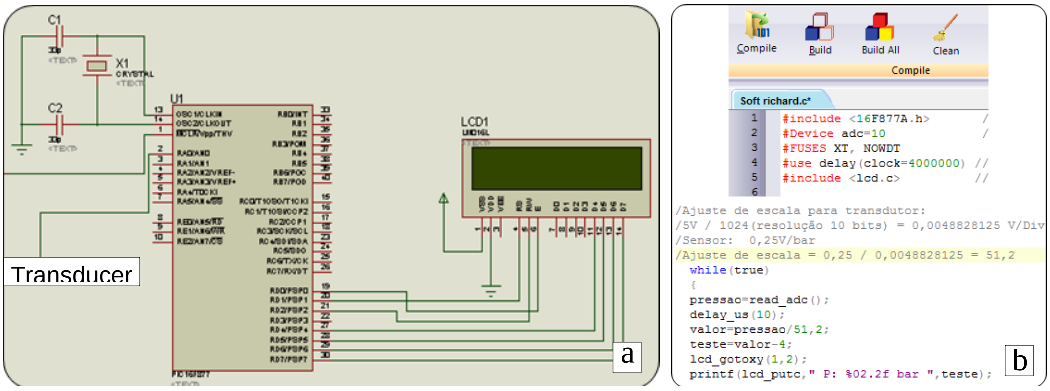


Fig.6. Pressure monitoring: (a) Hardware development platform and (b) Programming Platform

3. Analysis of Results

The following tables IV, V and VI express the results obtained during tests of manipulation, and the terms used in the field of analysis of the tables were set this way:

- Bad: The suction cup will not hold the sample, the same or dropped during handling.
- Critical: the sample has not fallen during handling, however, is a sash very close to the bad.
- Ideal: security level and all tests in this range, the system was stable and showed no change.

3.1. Suction cups of Silicone

Silicone rubber has a chemical structure consisting primarily of silicon and oxygen (Si-O), this structural formation is that justifies the broad range of temperatures and seal the excellent mechanical strength properties. These results can be seen in the results shown in Tab.III.

Tab. III. Results of tests done with the suction cup silicone

Pressure	Specimen (a) - slick		Specimen (b) - rough	
	0.5 kg	1 kg	0.350 kg	0.7 kg
	Vacuum/Analysis	Vacuum/Analysis	Vacuum/Analysis	Vacuum/Analysis
4 bar	-0.22bar/Bad	-0.22bar/Bad	-0.20bar/Bad	-0.20bar/Bad
5 bar	-0.30bar/Critical	-0.30bar/Critical	-0.28bar/Critical	-0.28bar/Critical
6 bar	-0.36bar/Ideal	-0.36bar/Ideal	-0.32bar/Ideal	-0.32bar/Ideal
7 bar	-0.34bar/Ideal	-0.34bar/Ideal	-0.38bar/Ideal	-0.38bar/Ideal

With these tests it was possible to show graphically with Fig.7 (a) the results obtained with manipulation of the slick glass and Fig.7 (b) with rough glass, using the silicone suction cup which was subjected to variations in pressure and manipulated load.

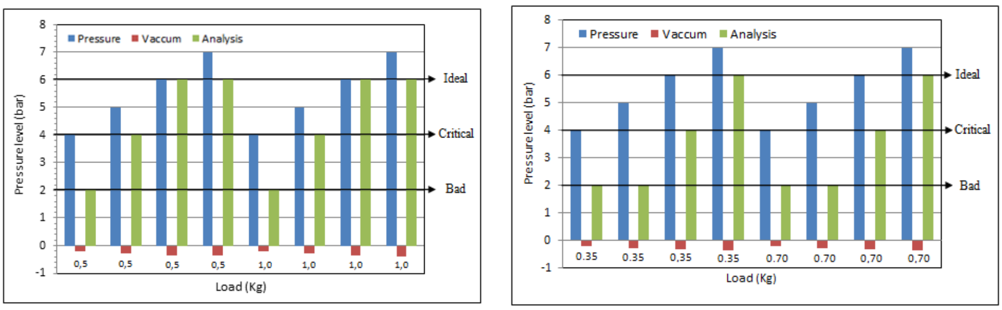


Fig.7. Vacuum suction cup with silicone: (a) slick glass and (b) rough glass

The results revealed that there was a high vacuum level in relation to the increased pressure, but this variation were the same even when the weight of material handled reached twice the recommended theoretical load, with the statement that the vacuum level is directly related with the level of pressure. It could be observed that the system with working pressures below 5 bar, did not achieve satisfactory results in any of the tests, making this unacceptable level of pressure to the handling system with these characteristics.
Regarding the results of cargo handled, we obtained acceptance with two of pressure levels considered optimal (6 and 7 bar), and these results are very satisfactory, noting that the burden of higher weight has twice the theoretical load recommended. With these results we can emphasize that the implementation of a vacuum handling system without conducting preliminary tests that confront theoretical data with super practical tend to scale the system in general, causing unnecessary expenses.
The results showed that just as there was a high vacuum level in relation to the increased level of pressure, and this amount has remained the same for both handling charges, but the system behaved differently in achieving the movement manipulation, and the tests performed on the roughened glass surface reached only a range of ideal pressure (7 bar), which also becomes satisfactory when referred to the difference of the manipulated loads, comprising at twice the recommended load theoretical.

3.2. Suction cups of natural rubber

By infrared spectroscopy, the spectrum found that the material used is a polymer with a polybutadiene characteristics and polymethylmethacrylate respectively with polybutadiene, the natural rubber compound. This material has characteristics of high elasticity, flexibility, resistance to abrasion and impact, having easy adhesion to fabrics and steel. However, this material (natural rubber) did not show a good performance regarding the tests performed with cut glass (Tab.IV), considering the same test conditions of the previous test.

Tab.IV. Results of tests done with the suction cup natural rubber

Pressure	Specimen (a) - slick		Specimen (b) - rough	
	0.5 kg	1 kg	0.350 kg	0.7 kg
	Vacuum/Analysis	Vacuum/Analysis	Vacuum/Analysis	Vacuum/Analysis
4 bar	-0,20bar/bad	-0,20bar/bad	-0,17bar/bad	-0,17bar/bad
5 bar	-0,30bar/critical	-0,30bar/critical	-0,22bar/bad	-0,22bar/bad
6 bar	-0,36bar/ideal	-0,36bar/ideal	-0,28bar/critical	-0,28bar/bad
7 bar	-0,39bar/ideal	-0,39bar/ideal	-0,30bar/ideal	-0,30bar/critical

Fig.8 shows the results of pressure levels (5 and 6 bar) which are related of the values of the degree vacuum and loading manipulated referring to the suction cups natural rubber and glass slick surface according to Tab.IV. Therefore, it is proven the accuracy of the tests and somehow identifies optimal parameters so that the vacuum handling system works within a safety range.

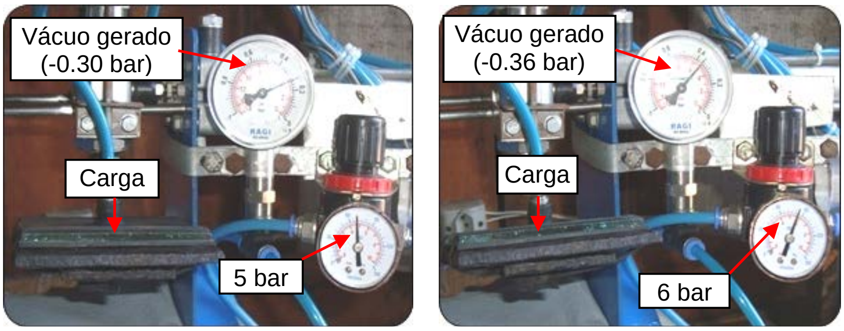


Fig.8. Levels of vacuum handling system

It is remarkable the difference between the vacuum level when the system undergoes a pressure variation. Fig.9 (a) and (b) shows the graph the results obtained with natural rubber suction cup with slick glass and rough glass.

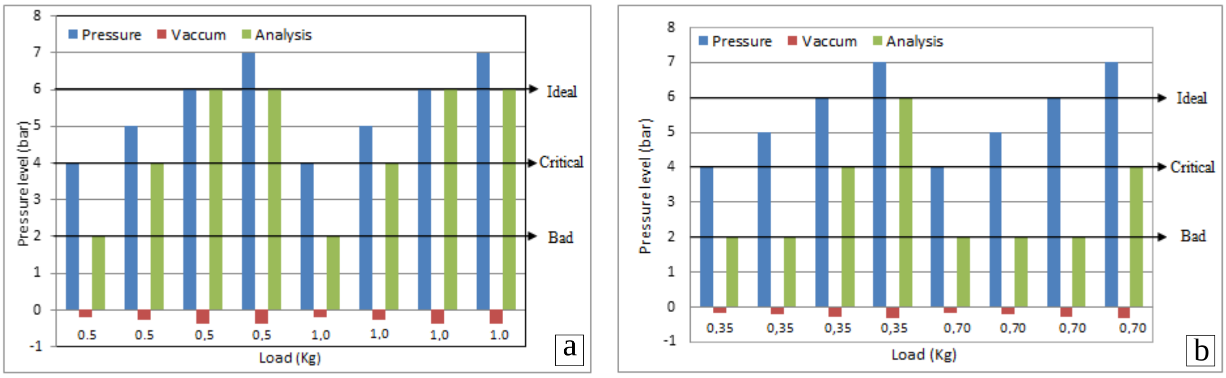


Fig.9. Vacuum suction cup with natural rubber: (a) slick glass and (b) rough glass

The results showed that in this case there was also a high vacuum level in relation to the pressure increase, and this change has remained the same, even when the weight of the material handled reached twice the recommended theoretical load.

Regarding the manipulated load, had the same results related to silicone suction cup, but the theoretical load raising and increase sizing two pressure levels were rated as ideal bar on 6 and 7, that is, very satisfactory results for the increase sizing reaches twice the recommended load.

With these values we can assign good features of the natural rubber suction cup compared to silicone, it had the same behavior in equal working conditions related to the slick glass, regarding the application the measurement of the roughness and weight manipulated the two have ideal working conditions, however the factor that must be analyzed to choose the correct suction cup, associated with their individual characteristics influencing the final results. The results Fig.9 (b) showed which were varying levels of pressure and weight of the load.

The results showed that there was a similarly high level of vacuum in relation to the increased pressure level, and this value remains the same for both handling loads. The system behaved differently in achieving the manipulation of which motions with increasing load of the glass rough surface results did not achieve any desired level of work, or for handling of the glass with this feature eliminates the possibilities of applying these parameters for loads above the recommended theoretical, making real the theoretical foundations used for handling system with these characteristics.

3.3. Suction cups of nitrile rubber

By infrared spectroscopy, the spectrum found that the material used is a polymer with characteristics of acrylonitrile and butadiene respectively nitrile compound (Ni). This material has characteristics that provide a good balance between resistance at low temperature (between -10°C and -50°C) with oil and solvents. Such combined with a good resistance to abrasion features make the nitrile rubber recommended for a variety of applications, particularly in locations that provide contamination part by oil or solvent.

In Tab.V mentions the tests performed with the nitrile rubber suction cup which was subjected to the same tests that the silicone suction cup.

Tab. V. Results of tests done with the suction cup nitrile rubber

Pressure	Specimen (a) - slick		Specimen (b) - rough	
	0.5 kg	1 kg	0.350 kg	0.7 kg
	Vacuum/Analysis	Vacuum/Analysis	Vacuum/Analysis	Vacuum/Analysis
4 bar	-0,20bar/Bad	-0,20bar/Bad	-0,17bar/Bad	-0,17bar/Bad
5 bar	-0,30bar/Critical	-0,30bar/Bad	-0,22bar/Bad	-0,22bar/Bad
6 bar	-0,36bar/Ideal	-0,36bar/Critical	-0,28bar/Critical	-0,28bar/Bad
7 bar	-0,39bar/Ideal	-0,39bar/Ideal	-0,30bar/Ideal	-0,30bar/Critical

Fig.10 shows the results obtained with the nitrile rubber suction cup, which was subjected to handling glass slick and the specimen with a rough surface, but with different loads and pressures.

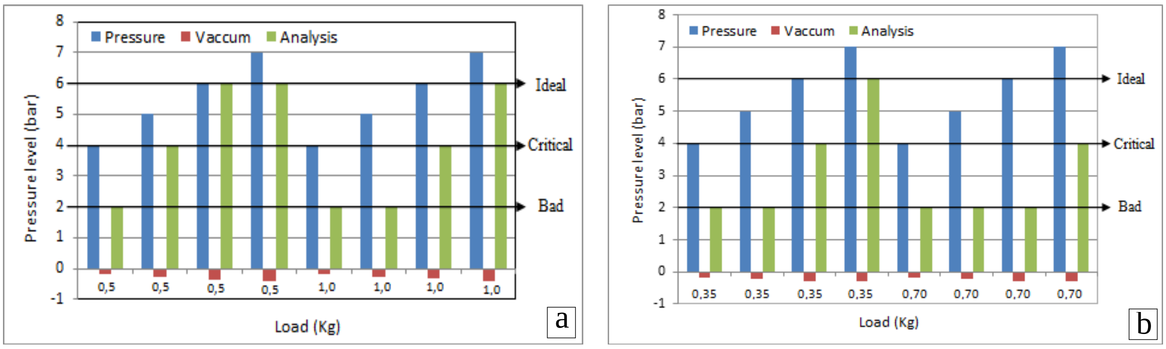


Fig.10. Vacuum suction cup with nitrile rubber: (a) slick glass and (b) rough glass

In the Fig. 10 (a) the results showed that in this case, there was still a high vacuum level relative to increased pressure in all tests, but this change was similar when the same weight of material handled reached twice the recommended theoretical load.

Regarding the charge of theoretical survey had two pressure levels classified as ideal and the load increment had only one ideal level of pressure, and those results also become satisfactory when reminded that the greatest burden is twice the theoretical load. In the manipulation of flat glass noted that sucker nitrile showed the same results regarding suction silicone and natural rubber with scaled theoretical load, and your choice will also depend on where it will be exposed.

In the Fig. 10 (b) the results showed that there was a high vacuum level in relation to the increased level of pressure, and this amount has remained the same for both handling charges, but the system behaved differently in achieving the movements handling and that with increasing load the roughened glass surface, the results did not achieve any desired level of work, to handling of the glass with this feature eliminates the possibilities of applying these parameters to loads above the recommended theoretically, making real the theoretical foundations used in the tests.

With these results it was observed that the suction cup silicone has chemical characteristics that increase their level of sealing in relation to other tested, being clear that the level of this vacuum in their tests was higher than that of other vacuum suction cups, even when handled rough glass surface with twice the recommended load.

Tab.VI presents the working ranges of the suction cup who presented the best results regarding the handling of slick and rough glass, the optimal parameters in relation to the work pressure, vacuum level generated and load handled with slick and rough glass.

Tab.VI. Classification of results in relation to the slick glass and rough

Materials	Pressure	Vaccum	Slick glass (0.5 kg)	Slick glass (1 kg)
Silicone	6 e 7 bar	-0.36 a -0.40 bar	Ok	Ok
Natural	6 e 7 bar	-0.36 a -0.39 bar	Ok	Ok
Nitrile	6 e 7 bar	-0.36 a -0.39 bar	Ok	Ok

Materials	Pressure	Vaccum	Rough glass (0.350 kg)	Rough glass (0.700 kg)
Silicone	7 bar	-0.38 bar	Ok	Ok
Natural	7 bar	-0.30 bar	Ok	Adeverse
Nitrile	7 bar	-0.30 bar	Ok	Adeverse

4. Final Consideration

According to the practical realization of the tests it was observed that the roughness of the material directly influences the performance of a handling system that uses vacuum technology , seen as the roughened glass had a mean Ra equivalent to 12.83 µm. Tests have shown that the results obtained with the specimen slick texture better had a utilization as the load capacity and the level of the working pressure, but the three suction cups had positive results with of this type, however, for the handling of glass rough texture the suction cup natural and nitrile failed to perform well when they exceeded the recommended theoretical loads.

In the results it was observed that the vacuum level behaved differently in relation to the change of the pressure level and the surface of each sample. The material obtained had a surface roughness values lower vacuum level as compared to the slick surface of the material even under conditions in which the pressure level remained the same.

It was also the vacuum level generated between the suction cup and the material influenced the capacity of cargo handled, as in the case of silicone suction cup that was the one that achieved positive results in all tests. This result shows that the key to be evaluated in a vacuum handling system parameter is the vacuum level generated between the suction cup and the piece, ie, for this type of roughness noted that to occur for the safe handling of the specimens system should produce a degree of vacuum less than -0.38 bar.

The three suction cups showed similar regarding handling of glass with a smooth surface by manipulation of the perceived double theoretical capacity results found. According to this we can say that the three types of materials suckers are able to operate in systems with these characteristics, since the optimal choice will depend on the environment that this suction cups will be exposed considering that each has a characteristic that can influence better results as its durability and productivity.

The results obtained with the manipulation of the rough surface of the material revealed that the suction cup silicone was the only one able to execute the tests with the two charges and establish optimum settings for the system, while the other two could only handle the theoretical value determined.

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