Volume 11, Number 7 (February 2018) p. 115 – 134 • ISSN 1983-4195
http://dx.doi.org/10.1590/S1983-41952018000100007

REVISTA IBRACON DE ESTRUTURAS E MATERIAIS
IBRACON STRUCTURES AND MATERIALS JOURNAL

Optimization of structural brickwork laying joints in concrete blocks

Otimização das juntas de assentamento de alvenaria estrutural em blocos de concreto




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Abstract

One of the challenges in the investigation of structural masonry is the correlation between the thickness of the laying joints and the global resistance of the masonry. Many authors developed experimental correlations in the attempt to establish an analytical relation between the joint thickness and the resistance of the masonry. All these projects indicate that there are many parameters and considerations to be analyzed in the understanding this relation and in understanding the collapse of the masonry as a whole. Thus, in an attempt to contribute with this field of study, the present paper investigates the influence of the thickness of the mortar laying joint in the resistance of the masonry structure.
With the objective of experimentally establishing a relation between the joint thickness and the resistance of the masonry, rupture trials were held to the axial compression of three block prisms laid with five series of thicknesses: 8mm, 12.5mm, 10mm, 15mm and 20mm. The physical and mechanic description of all the components that made up the masonry were done separately, complying with the regulations.
Through a simplified statistical analyses, presented at the end of this study, values of resistance of each series of prisms associated to a specific thickness for the laying joint are shown. Through the comparison of the specific results of the analyzed specimen, we arrived at the suggestion of a better performance joint and it was also possible to establish a behavioral tendency, through the comparison of results, helping in the understanding of how the block-joint set behave monolithically from the determination of the individual characteristics of each element. Which is one of the keys that will permit the constructions of a behavioral model capable of assisting structural analysts in their structural masonry dimensioning techniques.

Keywords: structural masonry, concrete blocks, laying joints.

Resumo

Um dos desafios na investigação do comportamento da alvenaria estrutural é a correlação entre a espessura da junta de assentamento e a resistência global da alvenaria. Vários autores desenvolveram correlações experimentais na tentativa de estabelecer uma relação analítica entre a espessura da junta e a resistência da alvenaria. Todos esses trabalhos indicam que existem muitos parâmetros e considerações a serem analisadas no entendimento dessa relação e no entendimento do colapso da alvenaria como um todo. Assim, pretendendo contribuir com esse campo de pesquisa, o presente trabalho investiga a influência da espessura da junta argamassa de assentamento na resistência da alvenaria estrutural.
Com o objetivo de estabelecer experimentalmente uma relação entre a espessura da junta e a resistência da alvenaria realizaram-se ensaios de ruptura à compressão axial em prismas de três blocos assentados com cinco séries de espessuras: 08 mm, 12,5 mm, 10 mm, 15 mm e 20 mm. E a caracterização física e mecânica de todos os componentes que constituem a alvenaria foi realizada isoladamente, atendendo as normas.
Através de uma análise estatística simplificada, apresentada ao final do presente trabalho são mostrados os valores de resistência de cada série de prismas associados a uma espessura específica para junta de assentamento. Através da comparação entre os resultados específicos dos corpos de prova analisados, chegou-se a sugestão de uma junta de melhor desempenho e também foi possível estabelecer uma tendência de comportamento, auxiliando a compreender como o conjunto bloco-junta se comporta monoliticamente a partir da determinação das características individuais de cada elemento. O que é uma das chaves que permitirá construir um modelo de comportamento capaz de auxiliar os analistas estruturais em suas técnicas de dimensionamento da alvenaria estrutural.

Palavras-chave: alvenaria estrutural, blocos de concreto, juntas de assentamento.

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Received: 15 Oct 2016 • Accepted: 23 Jun 2017 • Available Online: 15 Feb 2018

1. Introduction

Structural brickwork is a constructive process, in which components are used to seal the construction and to resist forces simultaneously. Although it's a millennial technique, the labor-saving use with dimension and calculous methodology is recent. Nowadays, with the advancement of techniques and material, in addition to the governmental impulse towards habitation construction, brickwork has been applied more often, for it presents benefits such as, easiness of execution, rationality and resource reduction in the project execution [1].

The structural masonry is designed to withstand stress, it has excellent ability to withstand the compression demands; however, for tensile stresses, its strength is much lower, and in some cases, it is necessary to use grate and reinforced. In this sense the material quality and thickness of the laying joint is fundamental, considering that the traction efforts that generally provoke block collapse begin in the superior or/and inferior sides of the block, exactly on connecting sides between one block and the other [1].

The main parameter for the dimensioning of the brickwork is in its resistance to compression that plays a role in the quality and resistance of its constituent components: the block and laying mortar, as well as the thickness of the joints. In Brazil, the use of hollow concrete blocks and the laying with a mixture of mortar and chalk gained popularity, the Brazilian standard NBR 15961-1 [2] recommends the use of joints with thickness of 10 mm with variation of + - 3 mm [3].

Many authors such as Medeiros and Sabbatini [4], Freitas [5] studied the prisms' behavior as to the joint thickness function and verified that the increase of the thickness causes a considerable reduction to the brickwork's resistance. However Mohamed [6] highlights that a loss of the mortar's deformation absorption capacity may occur if the joint reduction is excessive, and the increase of tension on the points where the block sides connect.

Duarte [7] rejects the above joints of 15mm, because he considers that they cause an increase in cost and a reduction of the brickwork's resistance; due to the fact that the mortar is the weakest part of the brickwork.

At the end of the present paper, it is shown the resistance value of each series of prisms associated to a specific thickness for the laying joint. Through the comparison of specific results of the trial bodies analyzed, we arrived at a suggestion of a better performance joint and it was also possible to establish a behavioral tendency through the comparison of results.

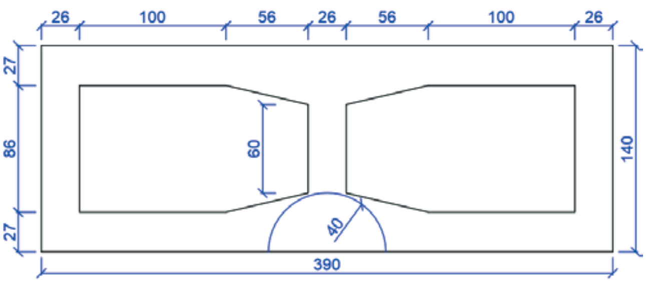

Figure 1
Studied commercial block face dimension (mm)

2. Material and experimental program

The experimental program of the present work is inserted in a line of research that studies the efficiency and integrity of structural masonry. With regard to the optimization of joints, this research line has been studying the variation of traces and thicknesses since the works of Oliveira [8] (2006), Oliveira [9] (2014), Bandeira [10] (2014) , Souza and Nunes [11] (2015), Francisco and Soares [12] (2016); allowing the construction of a database that correlates the different joint thicknesses with the mechanical and service performance of the masonry. Thus, this work, in addition to using the results collected will contribute with new data for continuity of the line of research through future work.

2.1 Dimensional description of the blocks

The blocks used in this study were acquired at a regional factory of pre-molded blocks, in order to study the same blocks that are commercially used by local construction companies. A dimensional analysis was done for these blocks and a visual inspection in accordance with orientation of the NBR (Brazilian Association of Technical Standards) 6136 [13], through which was verified that they did not present any defect or pathology that would compromise the trials.

Figure 2
Block with plaster capping

In a random sample of 10 blocks the length, height and width of the transversal and longitudinal walls were verified, as presented in Figure 1. The weight was determined in a digital precision scale, weighing at around 122 N.
None of the blocks of the sample presented a dimension that exceeded the tolerance allowed by the NBR 6136 [13] which is, ± 2mm for the width and ± 3mm for height and length, therefore the block can be categorized as belonging to the 15x40 family, with corbel. The brute section area of the block is 546cm2 and the liquid section area (brute section area minus the hollowed out holes) is 292.24cm2. The volume was geometrically determined by multiplying the liquid section area by the block height, coming out to 5552.56cm3. Ergo the specific mass has the value of 2186,38 kg/m³ and is in accordance to NBR 6118 [14].

2. 2 Mechanical description of the blocks

For the trial of axial compression, 12 block were chosen randomly of a lot of 200. Before the trial they undertook a regularization treatment of the superior and inferior sides with plaster, known as capping as shown in Figure 2; in which the paste mixed with 2kg of gypsum powder, glue and 1 Liter of water is applied with a help of a spatula, next the block is positioned on a table greased with vegetable oil where it's leveled. In accordance to NBR 6136 [13] the width of the capping layer did not exceed 3mm.
The capping serves the purpose of helping distribute the tension uniformly over the whole block and to avoid the concentration of isolated points. In addition to capping two 3mm sheets of cork were used during the severance. The plaster-cork set provided a compression force uniformity, minimizing the tangential efforts to the cargo application plain, which reduces the collapse possibility by tangential sheering on the top or bottom of the block [1]. Figure 3 shows the block's rupture scheme.
The rupture was made in accordance to the NBR 12118 [15] procedures, using a universal trial machine of the brand Contenco Pavitest with a maximum capacity of 100 tf. The squeezer was equipped with two rigid plates and the cargo increment was automatically applied at a speed of 0,25 MPa/s. Figure 4 shows the block during trial.
Of the 12 trialed blocks, the two highest and two lowest rupture tensions presented were discarded, leaving an 8 block set, with a more uniform rupture tension distribution. Simplified statistical analyses were done on the 8 remaining values that provided an average and characteristic value to the block's rupture tension that were used on further analyses of this project. This analysis is shown on Table 1 and Table 2, where fbm is the average tension to the simple compression of the block, fbk is the characteristic tension to the simple compression of the block, and Sd is the standard deviation. In accordance to the NBR 6136 [13], the blocks may be classified as belonging to Class B with structural function, namely, its average characteristic resistance (fbm) in relation to the brute area sits between 4 MPa and 8 MPa.

2.3 Description of the fine aggregate

According to Roman [16] the fine sands are preferable for making the structural brickwork laying mortar, due to the fact that they provide more adherence to the mortar. The aggregate used in this study is a local river washed sand, presenting a maximum diameter characteristic of 2.63mm and the fineness module is 2.86, it was trialed in accordance to NBR 248 [11]. Figure 5 shows the results of the granulometry of the aggregate utilizing the Utilization Zone Limits established by NBR 7211 [18].

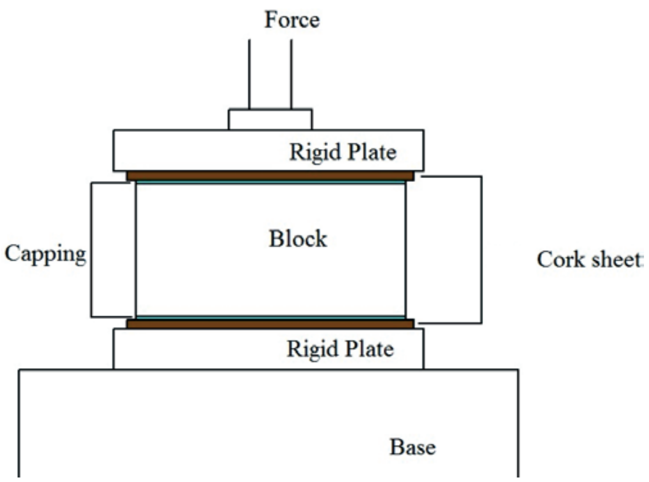

Figure 3
Axial compression trial procedure scheme with trial machine

Figure 4
Block axial compression trial

Table 1
Block compression trial results (Brute area = 546 cm²)

Block	Rupture cargo (kgf)	Tension (MPa)	fbm	Sd	fbk
B1	35090	6.43	6.25	0.41	5.84
B4	32560	5.96			
B5	37000	6.78			
B6	37460	6.86			
B9	32090	5.88			
B10	31580	5.78			
B11	34400	6.30			
B12	32830	6.01			
B2	25910	–	Discarded		
B8	27600	–			
B3	41500	–			
B7	41830	–			

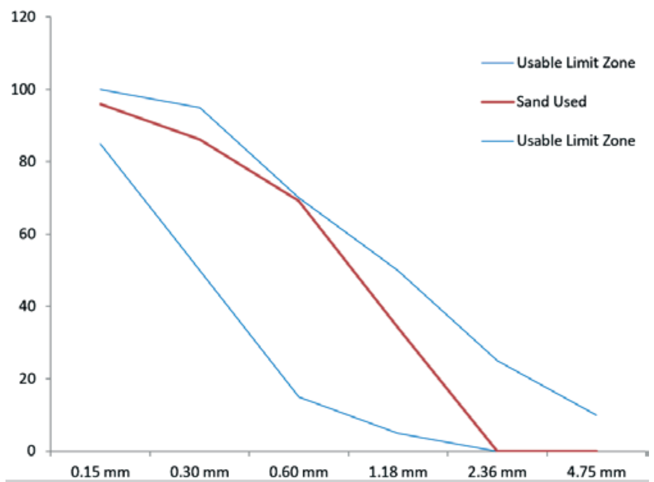

Figure 5
Granulometric composition graphic of the fine aggregate used for the mortar

2.4 Mechanical description of the laying mortar

The mortar used in the prisms' assembly is mixed and built on the spot, with a 1:0.4:5.72 (cement: chalk: sand) trait, with a weight and water to cement ratio of 1.6. The choice of the trait was made by taking in to consideration the frequency of the use of structural brickwork in regional construction. Cement CP II Z-32 was used, CH III hydrated chalk and medium washed sand. The trait was corrected in the mortar preparation due to the humidity of the sand, the mixture was done in a concrete-mixer, then the consistency and workability was visually verified.
For the mortar compression resistance verification, six proof bodies were molded in the dimension of 5x10cm, in accordance to NBR 7215 [19]. The rupture trials were held in the same test machine used for the block trials. Table 3 shows the proof bodies rupture cargos submitted to the compression test, the individual and average rupture tension, the standard deviation (Sd), as well as the characteristic resistance description of the mortar (farg).

2.5 Prism compression trials

The prisms' axial compression trials were held in order to evaluate the resistance capacity of the brickwork for each thickness of the laying joints. These trials were held in accordance to NBR 15961-2 [20] and NBR 12118 [15].

Table 2
Block compression trial results (Liquid area = 292.24 cm²)

Block	Rupture cargo (kgf)	Tension (MPa)	fbm	Sd	fbk
B1	35090	12.01	11.68	0.77	10.91
B4	32560	11.14			
B5	37000	12.66			
B6	37460	12.82			
B9	32090	10.98			
B10	31580	10.81			
B11	34400	11.77			
B12	32830	11.23			

Table 3
Mortar proof bodies compression trial results (Section area = 19.63 cm²)

Proof body	Rupture cargo (kgf)	Tension (MPa)	fma (MPa)	Sd	farg (MPa)
I	500	2.55	2.36	0.36	2.00
II	480	2.45			
III	490	2.50			
IV	500	2.55			
V	320	1.63			
VI	490	2.50			

50 prisms of 3 blocks were assembled, with five different laying joint thickness. Although some authors use two blocks prisms, it's been adopted in this work the use of three blocks prisms, since this procedure was more adequate in obtaining results closer to the reality of the masonry reality by approaching more of the real configuration of masonry. Awareness was given to the possible variables that could interfere in the prisms' resistance, such as, skilled labor, thickness execution templates, plummet and flatness. The blocks were previously dampened in order to avoid the mortar's water absorption.

After assembly, the prisms were identified and undertook a 14-day curation period, after they were submitted to compression trials under the same contour conditions of the block compression trials, as shown in Figure 6.

3. Results and discussions

3.1 On the prism trials

On Tables 4, 5, 6, 7, and 8 the rupture cargo for each prism is

Table 4
20 mm laying joint thickness prisms

Prisms	Rupture cargo (kgf)	Tension (MPa)	fpm (MPa)	Sd	fpk (MPa)
2	11040	3.80	3.47	0.39	3.07
3	8600	2.90			
4	9150	3.10			
7	11510	3.90			
9	10230	3.50			
10	10440	3.60			
1	13710	4.70	Discarded		
5	7340	2.50			
6	13800	4.70			
8	7410	2.50			

Table 5
10 mm laying joint thickness prisms

Prisms	Rupture cargo (kgf)	Tension (MPa)	fpm (MPa)	Sd	fpk (MPa)
11	22090	7.60	7.03	0.84	6.19
12	23830	8.20			
13	18220	6.20			
15	17510	6.00			
17	21380	7.30			
19	20020	6.90			
14	32030	11.00	Discarded		
16	10360	3.50			
18	14330	4.90			
20	26870	9.20			

shown, the individual rupture tension values and the average rupture tension value for the associated prism set (fpm) according each laying joint thickness. In order to calculate the average tension of each thickness group, the same procedure was adopted as the one used in the blocks, characterized by discarding the values of the two largest and the two lowest burst stresses presented, it provided a more uniform statistical distribution, composed of a set of 6 prisms. The characteristic resistance value of simple compression of each series of prisms (fpk) is also shown.

Figure 6
Axial compression trial of three block laid prisms

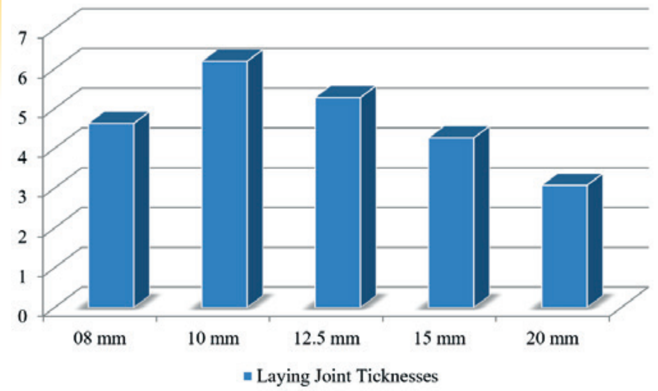

Figure 7
Performance comparative graph of joint related prisms with different thicknesses

3.2 Tendency

The results relative to the avarege resistance to compression of the structural brickwork prisms (fpm) for the different thickness joints, as well as the standard deviation (Sd) and characteristic resistance (fpk) are shown on Table 9.
The results of the relation between the prism ruptures and the joint thickness, follow the tendency shown by Ramalho e Corrêa [3], Medeiros [4] e Mohamad [6], where it is verified that the bigger the thickness the lower is the resistance achieved by the set. In this project, in addition to verifying this behavior, an investigation on what occurs with the unusual thickness of 8mm, that also suffers from a loss of resistance was performed. This tendency can be evidenced on Figure 7.

3.3 Efficiency

The brickwork efficiency is obtained by the reason between the prism resistance (fpk) and the block characteristic resistance (fbk). Table 10 shows the value of the brickwork's efficiency for the prisms tested in this project. The ideal efficiency according to

Table 6
8 mm laying joint thickness prisms

Prisms	Rupture cargo (kgf)	Tension (MPa)	fpm (MPa)	Sd	fpk (MPa)
21	18720	6.40	6.30	1.67	4.63
23	14790	5.10			
26	11440	3.90			
27	18290	6.30			
28	25270	8.60			
29	21930	7.50			
22	7870	2.70	Discarded		
24	27250	9.30			
25	6180	2.10			
30	29250	10.00			

Table 7
12.5 mm laying joint thickness prisms

Prisms	Rupture cargo (kgf)	Tension (MPa)	fpm (MPa)	Sd	fpk (MPa)
32	20250	6.90	6.35	1.07	5.28
35	12770	4.40			
36	18580	6.40			
38	17620	6.00			
39	20660	7.10			
40	21360	7.30			
31	23710	8.10	Discarded		
33	10070	3.40			
34	9990	3.40			
37	22340	7.60			

Table 8
15 mm laying joint thickness prisms

Prisms	Rupture cargo (kgf)	Tension (MPa)	fpm (MPa)	Sd	fpk (MPa)
41	14260	4.9	4.75	0.48	4.27
42	12210	4.2			
45	15830	5.4			
47	12220	4.2			
48	13750	4.7			
50	14900	5.1			
43	9240	3.2	Discarded		
44	9670	3.3			
46	17520	6			
49	17350	5.9			

Camacho [21], should present values between 0.50 to 1.00.
Among the prism series investigated, the one that presented a superior efficiency level to the minimum required by Camacho [21] was laid with a 10mm joint. This verification follows the tendency presented in Figure 7, where the thickness of 10mm was the one that presented the best result for the prism resistance. However, [15] does not offer further detail as to how the block and prism resistance are singly obtained.
According to Mohamad [6] the mortar resistance and the block resistance to compression should be compatible, if not it would result in a brickwork efficacy loss.

3.4 8 mm thickness behavior

This is the thickness that provides the biggest saving due to the lower use of mortar quantity. However, the saving generated by the reduction of the joint thickness should not be considered, for along with it comes a 25% loss of resistance in relation to the 10mm thickness.

3.5 10 mm thickness behavior

This presented the best mechanical behavior with a considerable

Table 9
Joint related results

Thickness	fpm (MPa)	Sd	fpk (MPa)
8 mm	6.30	1.67	4.63
10 mm	7.03	0.84	6.19
12.5 mm	6.35	1.07	5.28
15 mm	4.75	0.48	4.27
20 mm	3.47	0.39	3.07

Table 10
Joint related prism efficiency

Thickness	fpk (MPa)	fbk (MPa)	fpk/fbk
8 mm	4.63	10.91	0.42
10 mm	6.19		0.57
12.5 mm	5.28		0.48
15 mm	4.27		0.39
20 mm	3.07		0.28

elevated resistance when compared to the lowest resistance. It's the most useful thickness from a structural, economical and executional point of view. If compared to the 8mm thickness the rise in mortar consumption is insignificant if the gain in resistance is taken under consideration.

3.6 12.5 mm thickness behavior

This has a high difficulty level of execution in construction sites. When compared to the 10mm thickness there's a decrease in resistance and an increase in mortar consumption.

3.7 15 mm thickness behavior

It is used in structural brickwork construction sites in the Anápolis-GO region due to the low difficulty level of execution .However, in this study the prisms laid with this thickness presented a mortar graining tendency and low resistance; furthermore, the thickness may be considered economically inviable.

3.8 20mm thickness behavior

It was observed that many prisms of the 20mm group presented mortar graining during compression as shown in Figure 8. Such behavior is due to lower tension of confinement in which the mortar is submitted.

3.9 Comparative presentment of the trialed prisms

On the basis of the hypothesis that the 10mm thickness is the best thickness, Table 11 was made to show the comparison of the prism sets resistance, having this thickness as the foundation. It can be evidenced in Figure 9 that the rise and/or saving of laying mortar is not proportional to the resistance variation. All of the tested thicknesses presented a significant decrease in resistance in relation to the 10mm thickness.

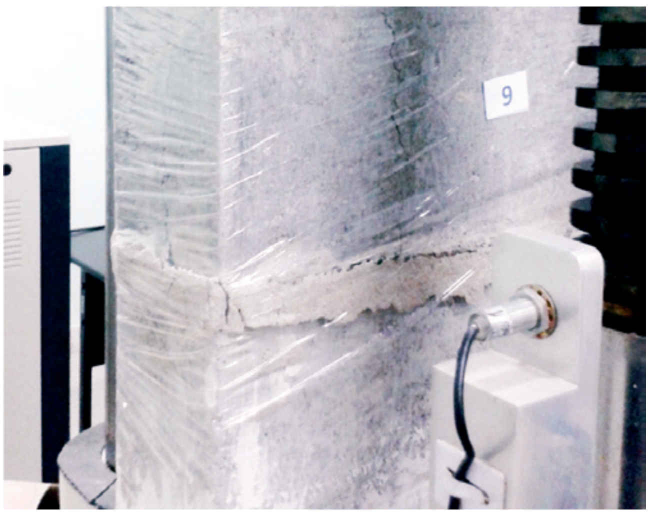

Figure 8
20 mm thick joints of laid prisms, presents mortar graining characteristic to this series

4. Conclusion

Out of all the thicknesses studied the 10mm present a higher resistance and efficiency of the brickwork. The three block prisms presented results that are closer to the brickwork's behavior. The behavioral tendencies of the prisms as to the joint thickness presented in this project are in accordance with the results of Castro [22] and Vicente et.al [23]. It's necessary to further investigate the behavior of the prisms with joint thicknesses lower than 10mm, since this project only investigated a series of 8mm. The presented results were obtained with the block resistance approximately five times greater than the mortar resistance, making it necessary to repeat the trial series with other mortar traits to verify if the same tendency repeats itself with more resistant mortars.

5. Acknowledgements

The development of this research was made possible through research funds granted by CNPQ and FUNDADESP/UniEvangélica and of blocks supplied by VIBRACOM company. In addition to the facilities and equipment from the Civil Engineering Lab of UNUCET/UEG and the Technology Center of UniEvangélica, as well as the collaboration of their respective technicians.

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Table 11
10 mm thickness related resistance variation

	Resistance variation (%)	Material consumption (%)
8 mm	-25.23	-20
12.5 mm	-14.69	+25
15 mm	-31.12	+50
20 mm	-50.37	+100

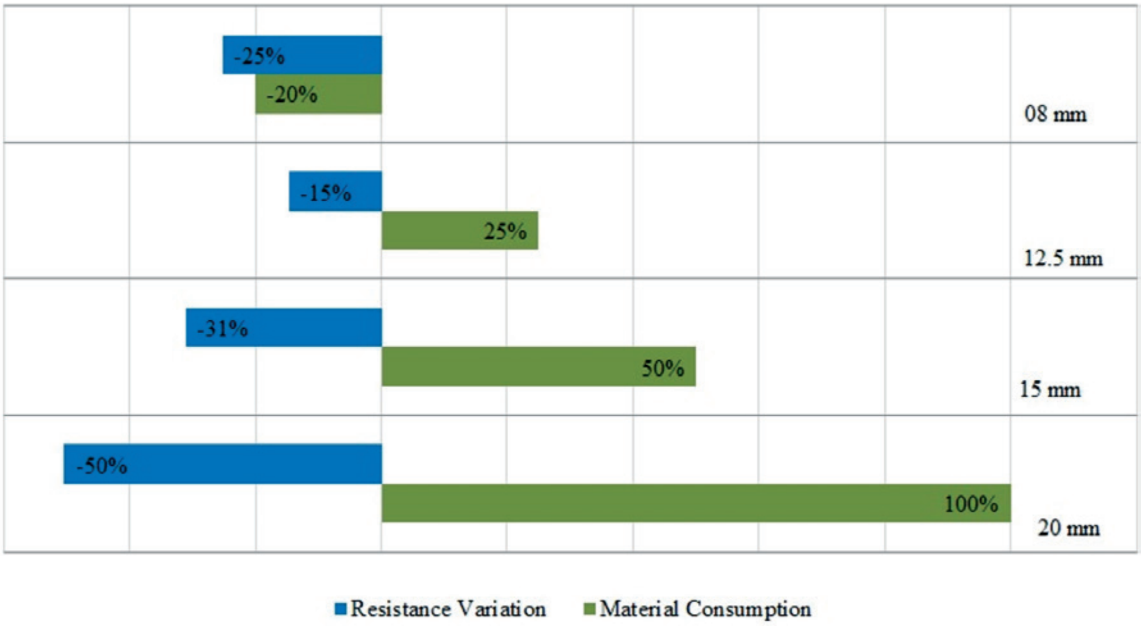

Figure 9
Performance comparative graph of thicknesses in relation to the 10 mm thickness

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