Faculdade de Engenharia e Arquitetura da Universidade FUMEC
Escola de Engenharia da UFMG
Faculdade de Engenharia da Universidade do Porto
ttp://www.fumec.br/revistas/construindo/index

ISSN 2318-6127 (online)
ISSN 2175-7143 (impressa)
Data de submissão em 20/03/2023
Aceito em 11/07/2023

EXPERIMENTAL INVESTIGATION ON THE BEHAVIOR OF MORTAR SUBJECTED TO SHEAR STRESSES

REIS, Elvys Dias
Federal Center for Technological Education of Minas Gerais (CEFET-MG)
elvysreis@yahoo.com.br

RESENDE, Heron Freitas
Federal Center for Technological Education of Minas Gerais (CEFET-MG)
heronfr@hotmail.com

da SILVA, Roberto Marcio
Federal University of Minas Gerais (UFMG)
rms2003@ufmg.br

ABSTRACT

Considering the increasing need to produce more resistant, durable, and sustainable materials, understanding the mechanical behavior of mortar has become essential, since it is a material widely used by the construction industry. Therefore, this work experimentally evaluates the behavior of mortar with expanding additive subjected to shear stresses. Specifically, it was sought to determine the maximum shear strength, analyze the type of rupture, and evaluate the method employed. The results indicated an average strength of 4.80 MPa, that the failure pattern was indeed shear, and that the method employed is simple and effective.

Keywords: Cement-based materials. Mechanical properties. Shearing resistance. Sustainability.

1. INTRODUCTION

Cement is a fundamental material in construction, and its use is widespread throughout the world. It is used in the production of concrete, a major building material, and used in a wide variety of construction projects, including buildings, bridges, roads, dams, airports, and many others (SIMÕES *et al*., 2017; TAI; EL-TAWIL; CHUNG, 2016). Portland cement production is an important sector of the world economy. According to data from the Global Cement Producers Association (GCCA), in 2020 world cement production was about 4.1 billion tons. China is the largest cement producer in the world, followed by India, the United States, and other Asian and European countries.

However, the use of cement has a significant impact on the environment, especially due to the CO_2 emissions generated during its production (REHAN; NEHDI, 2005). Concrete is the most widely used material in the world, but cement production emits approximately 7% of CO_2 on a global scale (IEA), 2020). Therefore, many efforts are being made to make cement production more sustainable and reduce its environmental impact, including the use of alternative materials and new production technologies.

In addition to the growing concern for environmental sustainability, the need to develop more resistant and durable building materials is an important issue in the construction industry (AL-MANSOUR *et al*., 2019; RESENDE *et al*., 2022). The partial replacement of cement with other materials, in this sense, has proven to be a viable solution. Blast furnace slag, for example, is a by-product of iron production and can be used as a cementitious agent in the production of concrete (BOUDJEHM *et al*., 2022; MING *et al*., 2020). Fly ash, another by-product of burning coal in thermal power plants, can also be used in concrete production as a partial substitute for cement (ASA *et al*., 2020; POTONG; RIANYOI; CHAIPANICH, 2022). In addition to reducing maintenance and repair costs, the use of these alternative materials can also reduce the carbon footprint of the construction industry (REIS *et al*., 2022).

It is important to note that the use of these alternative materials should be made with caution, ensuring that it does not compromise the quality and safety of the constructions. Therefore, studies on the composition and resistance of cement-based materials have been increasingly developed (GUO *et al*., 2022; IVORRA *et al*., 2021; METAXA *et al*., 2016; NGUYEN *et al*., 2020; YARDIM; LALAJ, 2016).

In this context, understanding the behavior of mortar subjected to shear stress is fundamental, since it is a material widely used in civil construction, employed in coatings, brick and block laying, and other applications. When the mortar is subjected to shear stresses, deformations, and internal tensions occur, which can compromise the stability and resistance of the construction (HIBBELER, 2010).

With this perspective, this work aims to evaluate the behavior of mortar with expansive additives subjected to shear stresses. Specifically, it seeks (i) to determine the maximum shear stress, (ii) to analyze the rupture type, and (iii) to evaluate the quality of the test method employed. By understanding the behavior of mortar subjected to shear stresses, it is possible to determine the strength and bearing capacity of the mortar in different loading situations. This allows engineers to correctly size structures and choose the appropriate materials to ensure the safety and durability of the construction.

2. MATERIALS AND METHODS

2.1. Materials

AC II type adhesive mortar, from manufacturer BR Massa, whose composition is Portland cement, well-selected mineral aggregates, and special non-toxic additives was used, simply by adding water to the mixture. This mortar is recommended for use in ceramic and tile laying, on floors and walls in internal and external areas, including facades, garages, and humid environments, meeting the specifications of the Brazilian standard NBR 14081 (ABNT, 2004a). Table 1 shows the mechanical characteristics of the mortar.

Table 1 – Mechanical characteristics of AC II type mortar

Parameter	Value
Adhesion strength per open time	> 20 minutes
Adhesion strength (normal curing)	> 0.5 MPa
Adhesion strength (submerged curing)	> 0.5 MPa

A powdered expanding agent for AC II mortar was used. The Centrament Expanding Agent additive, specifically, is commonly used for the production of expansive cementitious mortar to recompose, reinforce, and seal small cavities, such as cracks in buildings and civil construction. It is characterized by the formation of micropores in micro cement grouts. Its expansion is complete after approximately 2–4 hours and ensures optimal adhesion in any contact area. Due to pore formation, the strength of the material may be slightly reduced. Table 2 shows the technical data of the additive used in this study, all data referring to a temperature of 23±2 °C and 60±2% relative humidity. High temperatures and low humidity speed up the application time, while low temperatures and high humidity slow it down (ABNT, 2004b).

Table 2 – Technical data of the Centrament Expanding Agent additive

Parameter	Description
Physical state	Powder
Color	Beige/Grey
Storage	Keep it in a covered, cool, dry place, away from extreme temperatures or heat sources, in its original, separate, sealed packaging.

2.2. Mix Compositions, Specimen Preparation and Test Procedures

The mixture was mixed in a watertight and clean environment, protected from sun, wind, and rain. Thus, 5.2 liters of water were added for each 20 kg bag of mortar, but the mixture did not present a good consistency. To promote a better action of the additives in the mixture, the already homogenized mortar was left to stand for 10 minutes. Then it was mixed again, along with the expansion powder additive, for 2 minutes. Metallic molds (Figure 1) were used to make 11 prismatic specimens with dimensions 7.5×7.5×10 cm.

Figure 1 – Metallic prismatic molds

In Brazil, there are no standardized test methods for evaluating mortar shear. Thus, the test procedure was performed according to Gonçalvez *et al*. (GONÇALVES, 2013). The tests were performed at 28 days in the Laboratory of Experimental Analysis of Structures of the Federal University of Minas Gerais, using a hydraulic press with a capacity of 300 kN, model DL 30000, from an EMIC manufacturer, coupled to a computer with TEST (TestScript) software.

The device was mounted on the hydraulic press, and the specimens were adjusted in an L-shape, connected to the base made of steel to guide the load applied by the equipment at a 45° inclination. The L-shaped device should be inverted to ensure that the load distribution promotes shear at the 45° inclination because if there is an inversion in the placement of the device, only the compressive strength effect will occur in the test. Figure 2 shows the test setup.

Figure 2 – Test setup: (a) Side view; (b) Front view.

(a) (b)

After the specimens are mounted and attached, the hydraulic press applies a load to the device at a loading rate of 0.01 mm/sec, which shears the specimen, and this constant loading rate ensures a homogeneous flow of load over the part. When the rupture occurs, the rupture force (P_{rup}), in N, is measured, and, knowing the sheared area (A), in m^2—measured for each specimen after failure—, the shear stress (τ_{max}) is calculated by Equation 1.

$$\tau_{max} = \frac{P_{rup}}{A} \quad (1)$$

3. RESULTS AND DISCUSSIONS

Table 3 presents the maximum shear stress results obtained for the 11 specimens, as well as the descriptive statistics data (mean and standard deviation).

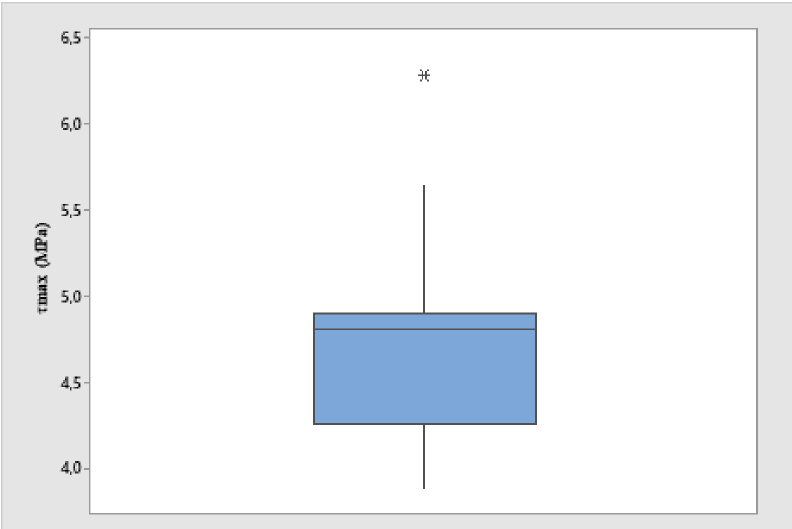
Table 3 – Maximum shear stresses of the mortar specimens

Specimen	τ_{max} (MPa)	Specimen	τ_{max} (MPa)
1	3.88	7	4.25
2	3.98	8	4.81
3	6.29	9	5.64
4	4.44	10	4.44
5	4.90	11	4.90

6	4.81	-	-
Mean			4.76
Standard deviation			0.67

As shown in Table 3, the average value of the maximum shear stress was 4.76 MPa. However, the high standard deviation of the sample, equal to 0.67, suggests that some of the specimens presented spurious values and that statistically does not represent well the sample. Through a boxplot (Figure 3), it is observed that this value corresponds to Specimen 3 (6.29 MPa).

Figure 3 – Boxplot of mortar specimens under shearing test.

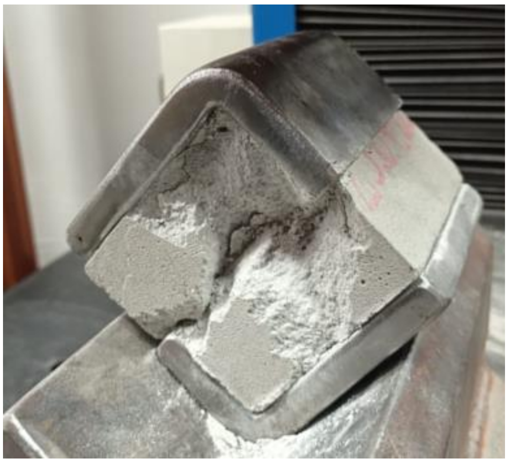


To compare the result obtained in this study with those in the literature, the authors chose to remove the spurious value of the specimen (Specimen 3) and recalculate the average shear stress. Thus, with the remaining 10 specimens, the new mean value obtained was equal to 4.60 MPa and the standard deviation was equal to 0.49. A new boxplot proved that there were no spurious values when considering this reduced sample.

In the study by Almeida *et al*. (2013), 4 prismatic specimens with the same dimensions as this study—7.5×7.5×10 cm—were tested for shear compression, also using the procedure of Gonçalves *et al*. (2013). These authors produced mortar with a mass ratio 1:0.6:6.57:1.37:0.008 (cement:lime:sand:water:additive) and, after 28 days of air curing, the specimens were tested and resulted in a maximum shear stress of 6.10 MPa (average), with a deviation of 0.48 MPa. Compared to the present study, it is noted that the average strength found by Gonçalves *et al*. (2013) was 27% higher. This difference may be related to the different mortar compositions, since the mortar of the present study was a ready mix (AC II type) plus the additive, while the mortar of these authors was dosed in the laboratory. However, it should be mentioned the low number of specimens used by the authors, whose sample standard deviation was equal to that of the present study, which tested more than twice as many specimens. Thus, taking into consideration the need to employ more resistant and durable materials, it is believed that the shear strength found in the present study seems to be reliable. The method employed is simple and can be used in further research, including numerical finite element models.

Regarding the type of rupture, Figure 4 represents one of the tested specimens, but the cracking pattern was the same throughout the sample. As in the study of Gonçalves *et al*. (2013), the cracks were formed at 45º in the internal longitudinal face of the specimen and a conical shape in the transverse face. These findings indicate that the experiment was successful, i.e., the rupture occurred by shear and not by another mechanism.

Figure 3 – Specimen ruptured by shear.



Moreover, knowledge about the behavior of mortar subjected to shear stresses can help to develop new materials and construction techniques that are more resistant and durable. This is especially important in regions prone to natural disasters, such as earthquakes and hurricanes, where resistance to shear stresses can be crucial to ensure the integrity of buildings and the safety of the people who live or frequent them. Therefore, the results of this research indicate that the test method employed led to good results and can be employed in future investigations, with mortars of different compositions. The authors suggest that in future research numerical models be performed to validate the results obtained experimentally so that the understanding of the behavior of mortar subjected to shear can be extrapolated. Studies of mortars with other types of reinforcement, such as natural and synthetic fibers, blast furnace slag, and nanomaterials, among others, are also indicated.

4. CONCLUSIONS

This work experimentally investigated the behavior of mortar with expansive admixtures subjected to shear stresses. The following conclusions can be drawn:

i. The maximum shear stress had an average value equal to 4.80 MPa. Compared to the literature and based on the number of specimens tested in this study, this value proved reliable.
ii. The cracks on the longitudinal faces of the ruptured specimens occurred at 45º, and the transverse faces had a conical pattern. This result is following the literature and suggests that the specimens ruptured in shear.
iii. The method used proved to be simple and effective, therefore, it can be used in further research.

It is important to emphasize that these conclusions are limited to the sample space used in this work, as well as the type of mortar employed.

REFERENCES

AL-MANSOUR, A. *et al*. Green concrete: By-products utilization and advanced approaches. **Sustainability (Switzerland)**, v. 11, n. 19, 2019.

ALMEIDA, R. S. DE *et al*. Avaliação da resistência ao cisalhamento em argamassas à base de cimento. **Iniciação Científica Cesumar**, v. 13, n. 1, p. 7, 2013.

ASA, E. *et al*. Development of sustainable construction material from fly ash class C. **Journal of Engineering, Design and Technology**, v. 18, n. 6, p. 1615–1640, 2020.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). NBR 14081: Argamassa colante industrializada para assentamento de placas cerâmicas - Requisitos. **ABNT**, 2004a.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). NBR 14082: Argamassa colante industrializada para assentamento de placas cerâmicas - Execução do substrato-padrão e aplicação de argamassa para ensaios. **ABNT**, 2004b.

BOUDJEHM, H. *et al*. Hardened properties of pre-cracked concrete incorporating metakaolin and crushed blast furnace slag as an additional blend material. **Construction and Building Materials**, v. 352, n. July, p. 129009, 2022.

Global Cement Producers Association (GCCA). **About Cement and Concrete - Key Facts**. Available in: https://gccassociation.org/key-facts/. Accessed in: March 19, 2023.

GONÇALVES, J. P *et al*. Proposta de método de ensaio para avaliação da resistência ao cisalhamento em argamassas. **Anais**. Anais...Fortaleza: 2013.

GUO, L. *et al*. Experimental study on pre-damaged RC beams shear-strengthened with textile-reinforced mortar (TRM). **Engineering Structures**, v. 256, p. 113956, 2022.

HIBBELER, R. C. **Resistência dos Materiais**. 7. ed. São Paulo: Pearson Education, 2010.

INTERNATIONAL ENERGY AGENCY (IEA). **The challenge of reaching zero emissions in heavy industry**. Available in: https://www.iea.org/articles/the-challenge-of-reaching-zero-emissions-in-heavy-industry. Accessed in: October 17, 2022.

IVORRA, S. *et al*. In-plane shear cyclic behavior of windowed masonry walls reinforced with textile reinforced mortars. **Engineering Structures**, v. 226, p. 111343, 2021.

METAXA, Z. S. *et al*. Carbon nanotube reinforced mortar as a sensor to monitor the structural integrity of restored marble epistyles under shear. **Procedia Structural Integrity**, v. 2, p. 2833–2840, 2016.

MING, Y. *et al*. Portland cement partially replaced by blast furnace slag and multi-walled carbon nanotubes: Effect on corrosion resistance of carbon steel reinforcement in 3% NaCl. **International Journal of Electrochemical Science**, v. 15, n. 9, p. 9003–9012, 2020.

NGUYEN, M. H. *et al*. Experimental evaluation of the shear capacity of perfobond strips with steel fiber-reinforced mortar in narrow joint structures. **Structures**, v. 28, p. 1173–1186, 2020.

POTONG, R.; RIANYOI, R.; CHAIPANICH, A. Properties of CNTs-modified lead-free BCTS ceramic–Portland fly ash cement composites. **International Journal of Applied Ceramic Technology**, v. 19, n. 6, p. 3334–3346, 2022.

REHAN, R.; NEHDI, M. Carbon dioxide emissions and climate change: Policy implications for the cement industry. **Environmental Science and Policy**, v. 8, n. 2, p. 105–114, 2005.

REIS, E. D. *et al*. Bonding of Carbon Steel Bars in Concrete Produced with Recycled Aggregates: A Systematic Review of the Literature. **C–Journal of Carbon Research**, v. 8, n. 4, p. 76, 2022.

RESENDE, H. F. *et al*. Uso de resíduos de construção e demolição como agregado reciclado no concreto: uma breve revisão de literatura. **Revista Principia - Divulgação Científica e Tecnológica do IFPB**; Early View, 13 out. 2022.

SIMÕES, T. *et al*. Influence of concrete strength and steel fibre geometry on the fibre/matrix interface. **Composites Part B: Engineering**, v. 122, p. 156–164, 2017.

TAI, Y. S.; EL-TAWIL, S.; CHUNG, T. H. Performance of deformed steel fibers embedded in ultra-high performance concrete subjected to various pullout rates. **Cement and Concrete Research**, v. 89, p. 1–13, 2016.

YARDIM, Y.; LALAJ, O. Shear strengthening of unreinforced masonry wall with different fiber reinforced mortar jacketing. **Construction and Building Materials**, v. 102, p. 149–154, 2016.