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ENVIRONMENTAL ENGINEERING

Potential reuse of industrial sludge in the production of ceramic floor mortar

INGENIERÍA AMBIENTAL

Potencial de aprovechamiento de lodos industriales en la fabricación de pegante cerámico gris para pisos

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Abstract

The growing generation of sludge from Wastewater Treatment Plants (WWTP) has become a great challenge for researchers in the last decades; this is mainly related to its special characteristics, which must comply with regulatory comprehensive management to eliminate any risk of negative environmental impacts. Therefore, it must be ensured that waste production has to be merged into productive cycles for their valorization and minimization of negative environmental impacts that may be generated by its poor disposal. The current investigation evaluated the incorporation of industrial and municipal waste sludge in ceramic adhesive manufacturing. Several attributes of sludge were evaluated and an experimental design (DOE) methodology was implemented to identify the quality of the glue by collaboration with the industrial company MAECOL. Experimental results showed that the most suitable sludge to replace a percentage of the conventional aggregates of the ceramic adhesive was the one produced by the company 2 of the metalworking sector; this was mainly due to the higher tensile strength obtained after the tests. It should be noticed that after the DOE study, the best tensile strength obtained after the runs was 0.34 MPa; this was achieved when 10% of the sludge was replaced In addition, it was observed that after replacing 20 and 30% of the sludge, the tensile strength decreased, nonetheless, to acceptable values.

Keywords: *Construction materials, Reuse, Sludge and waste water*.

Resumen

La creciente generación de lodos procedentes de Plantas de Tratamiento de Aguas Residuales (PTAR) se ha convertido en un gran desafío para los investigadores en las últimas décadas; esto debido a que, por sus características especiales, la regulación obliga a que se deba garantizar que haya una gestión integral para eliminar cualquier riesgo de producir impactos ambientales negativos. Por tanto, se busca asegurar que la generación de estos residuos sea incorporada a ciclos productivos para su valorización y disminución de los impactos ambientales negativos debido a su inadecuada disposición. La presente investigación evaluó la incorporación de lodos residuales industriales y municipales en la fabricación de pegante cerámico. Se evaluaron las diversas características de los lodos y se implementó un diseño experimental en colaboración con la empresa MAECOL para identificar la calidad de los pegantes. Se encontró que el lodo más adecuado para sustituir un porcentaje de los agregados convencionales del pegante cerámico es el producido por la empresa 2 del sector de metalmecánica, ya que se obtuvieron resistencias a la tracción mayores, siendo el mejor comportamiento cuando se reemplaza el 10% de este lodo (0.34 MPa). Además, se observó que después de reemplazar 20 y 30% del lodo, la resistencia a la tracción disminuyó, no obstante, a valores aceptables.

Palabras clave: *Aguas residuales, Aprovechamiento, Materiales de construcción y lodos.*

1. Introduction

The increasing amount of waste produced and the progressive emphasis on acting in accordance with sustainable development guides the research that must be carried out on new waste management concepts, which require them to be used in various industries as raw materials [1]. In the specific processes of water treatment, a considerable volume of by-products of different nature are continuously being produced, among which are the sludges from the Wastewater Treatment Plants (WWTP). The sludge, as a byproduct of the wastewater treatment process, has for many years been used primarily for use in agriculture and landfill [2]. New ways of using and valuing sludge are also being investigated, so that they can rejoin new productive cycles where their potential is being exploited, guaranteeing an environmentally sound, safe management and that are consistent with the social condition of the community and with the basic requirements that the system needs to be sustainable over time.

The implementation and development of new technologies related to the use of sludge are currently based on treating it as a substrate to reinstate it into new production processes [3]. One of the productive sectors in which sludge can be used is in the construction industry, which plays an important role in both developing and developed countries. Pro-environmental action and sustainable construction practices, as well as a growing demand for construction materials, are the factors that contribute to the use of by-products in this industry [4,5]. These have shown great potential to replace raw materials, since they reduce the costs of finished products such as Portland cement, masonry bricks, filling material for roads, among others [6]. In this investigation the feasibility of manufacturing a new construction material, ceramic glue for gray tiles, replacing the conventional raw material of filling or volume (marble, sand or other) by treated sludge generated in industrial WWTPs was studied.

2. Methodology

2.1. Sludge selection

Initially, for the selection of sludge from industrial WWTPs, the possible companies from which sludge samples could be taken were analyzed, based on the Cinara Institute database, specifically the Environmental Sanitation Research Group, who have developed two Previous projects on this topic. Sludge from 8 companies was studied, which are shown in Table 1.

2.2. Sampling and analysis

Sludge composite samples (several subsamples mixed in known proportions) were taken at each of the eight selected companies. Two types of sampling of the standard NTC 5667-13 [7] were established according to the conditions of the companies, the first sampling of piles of sludge, since two companies and the WWTP-C had this type of storage, while the second is sampling in containers, of which six companies complied with this storage.

2.2.1. Characterization

During this stage two types of characterizations were made, the first to identify the parameters of health interest and the second to analyze the physical and mineralogical parameters of the sludge. The characterization of health interest allowed identifying the main pollutants that can affect the environment and human beings. In this analysis, 22 parameters were measured between physicochemical and microbiological analysis of sludge in the CINARA Institute Water Laboratory. It should be noted that the sludge was analyzed separately, due to its different natures. Subsequently, the second phase of the characterization of the chemical and mineralogical properties of the sludge was carried out by means of the X-Ray Diffraction (DRX) and X-Ray Fluorescence (FRX) analyzes. In order to identify the potential of sludge to replace conventional raw materials in the manufacturing process of the ceramic glue and perceive what was its behavior and reaction with the other raw materials. From the results obtained in these characterizations, the sludge that showed the greatest potential in its composition to replace the aggregates of the glues was selected.

Table 1. *Participant companies*

Company identification	Industrial Sector	Location	Activity
Company 1	Automotive	Cali	Motorcycles, Auto parts, metal pipes
Company 2	Metalworking	Cali	Manufacture of screws in steel, copper among other raw materials
Company 3		Cali	Manufacture of metal structures and construction of civil works
Company 4		Yumbo	Extrusion and lamination of aluminum
Company 5	Foods and drinks	Cali	Manufacture of non-alcoholic beverages, production of mineral waters and other bottled waters
Company 6		Yumbo	Confectionery
Company 7	Textile	Yumbo	Preparation of clothing for women
Company 8	Paper and paperboard	Yumbo	Manufacture of household and industrial hygiene products

2.3. Experimental phase

The cementitious tile glue consists of two main components, the first one corresponds to the chemical base and the second is the material that provides volume to the product, also called aggregate. According to the formula supplied by the Company MAECOL SAS, the chemical base corresponds to an approximate percentage of 30% while the aggregates have a contribution of 70% in the final material, given the intellectual protection of this formula the contents of the chemical base cannot be revealed. Various percentages were evaluated to replace the material that gives volume to the mortar (aggregates), which corresponds to 70% of the final product. The technique selected for the design of this experiment was a design with factorial structure, since it is one of the most efficient studies for this type of experiment. In this investigation it was determined to use a single factor (type of treatment) and seven treatments, in order to evaluate the behavior of each of the glues manufactured with three percentages of sludge addition or without sludge addition, the latter corresponds to the glue or control treatment (conventional MAECOL glue). The sludge addition percentages were selected taking into account the recommendations of the material experts. Table 2 presents the experimental design.

2.3.1. Product manufacturing

MAECOL manufactured using its own formulas the seven types of cementitious tile adhesives [8] with the various specifications of the treatments, it should be noted that it cannot be reported due to the intellectual property protection of the formulas.

2.3.2. Product quality tests

The response variables constitute a fundamental factor in defining the feasibility of replacing conventional aggregates with a partial sludge fraction. Therefore, two important criteria were identified to define these variables, the first criterion was the most recognized properties that commercial market gluers reported in their technical sheets (contained in NTC 6050) [8,9] and the second was the various recommendations of the experts of materials. Taking these criteria into account, two response variables were defined, the tensile adhesive strength after immersion in the water and tensile strength after applying the material with an open time of 20 minutes. The determination of these parameters allowed to measure the quality of the new material (glue with sludge) obtained against the requirements of the standard present in NTC 6050. These tests were carried out in the Biotechnology Laboratory of the Tecnoparque node Cali of the SENA and were performed for each of the seven treatments described above.

According to NTC 6050-2 [9] it was necessary to build various cement blocks to simulate the cement surface on which the floor glue is normally applied. That is why, taking into account the seven treatments to be evaluated, its

Table 2. *Treatments of the experimental design*

Treatment	Sludge class used	Proportions by components	
		Sludge percentage	Percentage of aggregates
1	No sludge addition	0	100
5	Industrial	10	90
6		20	80
7		30	70

three repetitions and the two response variables, 52 cement blocks were manufactured (42 required in the tests and 10 for contingencies). The mixture of sand, cement and water was performed, using a water cement ratio of 0.5. Adhesive tensile strength is the maximum strength expressed in force per unit area, it can be measured in a tensile or shear test. This variable is determined for class C1 normal cementitious adhesives, with water absorption between 6% and 10% by mass fraction. It was also found that the most recognized commercial glues report it in their technical data sheets. The strength of the glue was measured following the lines present in NTC 6050-2, number 4.4.4.2 [(9)]. To obtain the values of total tensile load (F) the universal machine Hung Ta reference HT-2402 250KN and the UTM program (Universal Testing Manager) were used, where a specimen was created for this test taking into account the size of the blocks and a force at a constant speed of 250 ± 50 N / s.

Open time is one of the main characteristics of the adhesive for ceramic tiles. It is defined as the period of time after the spread of the adhesive on the concrete plate, within which the tile with the appropriate tensile adhesive resistance [(10)] can be placed. For its calculation, the guidelines defined in NTC 6050-2 numeral 4.1 were followed. To fix the traction heads (metal attachment) an extra-strong instantaneous glue was used and sand weights were used guaranteeing 20 ± 0.05 N. To obtain the tensile strength values, the universal machine Hung Ta reference HT-2402 was used. 250KN and the UTM program, where a specimen was created for this test taking into account the size of the blocks and a force at a constant speed of 250 ± 50 N/s. Finally, to calculate the final data of adhesive tensile strength and open time for each of the treatments, Eq. 1 was used. Rx being the resistances obtained in each of the tests (Newtons per square millimeters), F the load Total traction obtained in the universal machine in Newtons and A the area of union in square millimeters (2500 mm^2).

$$R_x = {}^{F}/_{A} \qquad \text{Eq. 1}$$

3. Results and discussion

It was identified that the generation of sludge in large quantities (> 100 Ton/year) occurs in companies that have a large installed and productive capacity, in particular company 8 presents the largest generation with 23,400 T/year, while the Company 1 of the automotive sector has the lowest values with 0.8 T/year 35% of companies implement final disposal techniques such as incineration, safety cell and landfill. On the other hand, the remaining 65% carry out various harvesting and treatment techniques in some cases outsourcing the external sludge management.

Table 3 presents the characterization made to the sludge of the 8 companies and the comparison with the characterization of the sludge of the municipal WWTP of Cali. The sludge from company 5 also presented high BOD5 values as well as COD values, which shows that almost all solids are due to the presence of organic material due to their normal food and beverage manufacturing processes, specifically in the washing of bottles for their reincorporation to the process. Company 6 reported the highest COD levels, however, this sludge did not show high levels of BOD_5, therefore, the solids load is not mainly composed of organic material, but another material of greater difficulty for chemical oxidation. The paper industry company (company 8) presented the highest total suspended solids load, mainly due to the high lignin and cellulose load of its production process.

Table 3. *Results of industrial sludge analysis*

PARAMETER		INDUSTRIAL SLUDGE								MUNICIPAL SLUDGE
		Company 1	Company 2	Company 3	Company 4	Company 5	Company 6	Company 7	Company 8	*WWTP-C*
Physiochemical	BOD (mg/g)	16.25	2.86	12.4	0.16	8.45	32.9	21.6	10.2	20
	QOD_5 (mg/g)	2.35	2.04	0.62	0.14	8.2	3.76	1.7	0.2	9.85
	Total suspended solids (mg/L)	0.09	0.01	0.02	0.53	0.08	0.29	0.1	88.3	0.07
	Volatile solids (mg/g)	156.68	130.84	304.62	30.92	81.75	260.04	80.9	561.8	160.63
	Nitrates (mg/g)	0.13	0.28	0.02	0.25	0.06	0.2	0	370000	0.02
	Total Nitrogen (mg/g)	0.27	0.13	0.17	0.31	7.37	3.79	0	400	1.34
	Nitrites (mg/g)	0.12	0.02	0.02	0.39	0.01	0.02	0.6	0.27	0.03
	Ammoniacal nitrogen (mg/g)	0.02	0.16	0.1	0.16	0.52	1.1	0.3	0.612	0.82
	Soluble Phosphorus (mg/g)	0.05	0.07	0.0005	0.0047	0.41	0.02	0.0466	0.01	0.17
	Particulate phosphorus (mg/g)	0.04	0	0.0014	0.67	2.31	1.5	0.0215	0.008	0.05
	Total phosphorus (mg/g)	0.09	0.07	0.0019	0.67	2.72	1.52	0.0007	0.01	0.22
	Fats and/or oils (mg/g)	78.69	4.25	0.13	0.3	0.56	79.97	0.0039	0.02	1.17
	pH (Units)	10.09	11.29	5.23	5.95	7.77	5.78	0.0047	0.04	7.71
	Total alkalinity (mg $CaCO_3$/g)	17827.87	5.55	1992.93	176.79	3.31	8.28	2.1	0.3	1.14
	Acidity (mg $CaCO_3$/g)	0	0	100.66	37.61	0.0003	0.01	10.5	7.87	0
	Conductivity (µs/cm)	28.4	2.99	27.9	105.9	5.17	2.25	67	4.8	1
	Total phenols* (mg/kg)	N.D< 0.07	N.D< 0.07	N.D< 0.07	N.D< 0.07	N.D< 0.07	N.D< 0.07	0	0	N.D < 0.07
Microbiological	Helminth eggs (N°/g)	0	0	0	0	0	0	183	371	0
	Total coliforms (UFC/g)	0	0	0	0	2297.01	5169.75	0	0	12000000
	Fecal coliforms (UFC/g)	0	0	0	0	0	281.99	0.2	N.D <0.111	3100000
Heavy Metals	Arsenic* (mg/kg)	4.14	59	0.24	0.39	107.67	310.28	3.7	0.321	0.9
	Cadmium* (mg/kg)	N.D< 0.77	1.18	N.D< 1.14	N.D< 0.75	13.97	1.84	N.D <0.97	2.3	N.D < 1.0
	Copper* (mg/kg)	740.3	26.25	46.03	20.07	61.77	69.05	2.4	52.1	58.9
	Chrome* (mg/kg)	329.2	259.3	120.97	44.78	19.1	13.88	4.8	7.2	11.5
	Mercury* (µg/kg)	83.4	241.45	124.99	62.12	67.14	99.76	N.D <0.887	0.098	0.4
	Molybdenum* (mg/kg)	49.13	28.03	11.96	29.88	42.8	45.29	N.D <23.37	N.D <44.32	N.D < 2.4
	Lead* (mg/kg)	649.95	N.D< 2.56	N.D< 18.11	N.D< 11.85	38.25	10.18	N.D <14.52	35.7	16.9
	Selenium* (mg/kg)	126.14	28.51	127.91	101.82	30.66	42.84	N.D <17.11	306.3	300.8
	Zinc* (mg/kg)	0.25	0.24	322.43	217.89	195.87	104.27	N.D <10.39	19.9	30

Since the sludge of companies 5 and 6 belong to the food and beverage sector, these were the ones that presented the highest levels of total nitrogen and phosphorus, which can generate eutrophication effects in the bodies of water that receive this type of waste without prior treatment. The sludge from company 6 showed, in general, high levels of heavy metals. Given that the automotive company 1 does not have PTAR, this sludge presented the highest levels of heavy metals, especially for cadmium, chromium and lead, which make it extremely dangerous for both human health and the environment. In general, the sludge of the metalworking companies, presented high levels of metals, on the contrary, the sludge of the company 7 did not yield significant results for heavy metals. The sludge of the metalworking company 4 was those that presented the highest levels of other forms of nitrogen in oxidation state: nitrates and nitrites, this may be due to the high amount of electrolytes used during their production process.

When assessing the danger of sludge, it was found that the sludge obtained from company 1 and company 6 showed high levels of heavy metals and coliforms, which makes handling and incorporation into productive chains difficult without prior conditioning. For this reason, it was decided not to continue investigating the by-products of these two companies.

3.1. Mineralogical and chemical characterization

In the results obtained by the X-ray fluorescence technique, it can be observed that they have high ignition losses (LOI), attributed to volatile phases, to dehydroxylation of clay phases and of hydroxides of aluminum, iron, and decarbonation. The sludge of company 4 has a high amount of aluminum oxide, which can benefit the reactions of the cement when it comes into contact with the fine particles of the sludge. While the by-product of company 2 is mainly composed of silicon, aluminum and iron oxides which make it attractive to be used as a fine aggregate in cement mortars, due to the possibility that the fine fraction (less than 45 μm) react with cement to improve strength.

The municipal sludges of the WWTP are mostly composed of organic matter, silicon oxides and aluminum oxides, which is consistent with what was reported by Amin [11] that found that the municipal sludge generated in Cairo, Egypto had a content high organic matter according to reports of losses due to ignition (65%). It should be noted that the reports of specific FRX results for industrial sludge of different productive activities linked to this research are limited, which is why the results of the most documented industries were contrasted, in this case it was the metalworking or also called galvanic productive sector. According to the diffraction patterns, the industrial sludge of company 3, 7 and 8 exhibit greater crystallinity in their microstructure, which may be of benefit at the time of making the mixtures, since it would be expected that it would not have a reaction with the base Chemistry, like aggregates. On the other hand, samples of industrial sludge from company 2 show different crystalline peaks in their diffraction patterns.

According to the mineralogical analysis of the sludge reported by the IGAC laboratory, it is observed (Table 4) that the samples from company 7 and 8 contain a large amount of calcite (calcium carbonate $CaCO_3$) 79.45% and 87.59% respectively. This compound is commonly used as filler or filler in addition to cementitious materials, which is responsible for mechanical resistance at an early age in these materials; therefore, these two sludge have a high potential from the mineralogical point of view. On the other hand, the sample of company 7 presents 4.36% clay, which can delay the setting reactions and high demand for water in

Table 4. *Results of mineralogical analysis of sludge samples by DRX*

Mineral	Sludge sample (%)						
	WWTP -C	Company 2	Company 3	Company 4	Company 5	Company 7	Company 8
14 Å CLAYS	-	2.97	-	-	5.20	4.36	-
MICAS	1.93	3.79	-	20.84	10.22	1.04	0.05
PYROPHILITE	2.66	-	-	-	9.38	2.15	-
GIBSITA	-	-	5.61	-	-	2.17	-
CHRISTOPAL	5.84	5.10	-	-	9.58	1.56	-
QUARZT	45.12	42.42	3.54	-	23.20	4.43	-
CALCITA	5.74	4.67	-	-	7.43	79.45	87.59
APATITE	1.67	-	-	-	9.62	4.83	-
CHLORITES	1.85	-	1.77	26.79	-	-	-
ANPHIBOLS	1.97	-	1.87	-	8.76	-	-
METAHALOISITE	6.11	15.19	-	-	-	-	-
CAOLINITA	3.65	-	-	-	7.17	-	-
LEPIDOCROCITA	1.32	-	-	-	-	-	-
FELDESPATOS	13.82	21.87	80.70	13.78	-	-	3.52
DOLOMITE	5.60	-	-	-	-	-	4.68
HEMATITE	2.73	3.98	-	-	-	-	-
HALITE	-	-	6.50	38.60	-	-	4.16
GOETHITA	-	-	-	-	9.45	-	-

the cement in case of plastic clays. The other minerals that present these to a lesser extent are inert materials, which are aluminosilicates that are in a crystalline state as shown by the diffraction patterns of both samples. The sludge of company 3 contains a high percentage of feldspars and iron ores, which correspond to sodium, potassium or calcium aluminosilicates, and according to the diffraction pattern they have a crystalline microstructure which makes this phase inert with Portland cement. However, this sample has 6.5% of Halite (mineral salt) that can generate opposite reactions when this sludge is mixed with Portland cement, due to the chlorine ion it possesses.

Samples of company sludge 2 and municipal sludge have similar amounts of minerals, with quartz predominant, in quantities of 45.12% and 42.42% respectively, and also has significant amounts of metahaloisite, which is a silico-mineral meta-stable aluminous with a certain degree of reactivity. However, the municipal sludge has clay phases that could hinder the action of the cementing agent, deteriorating the mechanical properties. Finally, the samples of companies 4 and 5, according to the mineralogical analysis, show quantities of different silicates and salts. From the chemical (FRX) and mineralogical (DRX) characterization, it was identified that the industrial sludge that presented the greatest potential in their compounds and structures to be incorporated into the glue as aggregates are the residual sludge of companies 2 and 4.

On the other hand, the sludge of company 3 is a material rich in iron oxide (72%), because it is from the metalworking industry, iron oxide is a material that sometimes reacts with cement; however, these reactions occur at long ages. It was found that the beverage industry (company 5) has a sludge that presents a high loss due to ignition, attributable to organic or clay material, which makes it chemically unfeasible to be used in combination with cement. In addition, it has a high percentage of sulfate (SO_3), which can generate expansions in hardened cement due to the formation of expansive products such as taumasite. It can be evidenced that the sludge produced in the metalworking industries (company 2, 3 and 4) report a quantity of some similar elements and others quite divergent. This may indicate that although they belong to the same productive sector there are many variables that influence the processes that can generate great divergences. This situation could be contrasted with various results reported in previous investigations, where it was found that a company dedicated to chroming reported that the chemical elements with the greatest presence in the sludge were CaO 18.11%, Cr 12.71%, Cu 5.85 % and Ni 4.71%. They also found a content of 24.52% organic matter [12].

3.2. Quality tests of cementitious adhesives

From the results of the characterization and preliminary tests (resistance to compression in mortars), it was decided to continue the investigation with the industrial sludge 1, making replacements for the fine aggregate in the ceramic glue in percentages of 10, 20, and 30% in each sludge.

3.3. Tensile strength after open time in sludge binders

Table 5 shows the resistance values after open time for municipal and industrial sludge. The best resistance was obtained with 20% municipal sludge (0.34 MPa), followed by a similar value (0.31 MPa) when 30% industrial sludge was used. However, a clear trend is not observed when comparing the resistance of each sludge, it is also found that the resistance with the other percentages in the two sludge is very low, mainly in the industrial sludge, the difference is of the order of 10 times. This situation is attributed to the inadequate application of the load when the ceramic was glued. The best result obtained in the two sludge (0.34 and 0.31 MPa), is acceptable in the resistance of floor glue, although it does not comply with the recommendations of the NTC 6050 standard (0.5 MPa), but it should be clarified that they are not mandatory. The coefficient of variation (CV) is lower in the 30% industrial sludge test is only 2.62%, while that of the other tests was above 15%.

3.4. Tensile strength after immersion in water in sludge sticks

With the industrial sludge, adequate resistances are obtained (Table 6), the best behavior being when 10% of this sludge is replaced (0.34 MPa); when used in 20 and 30% resistance decreases, however, all values are acceptable. The variability of the data is high in all replacements, especially for 20% industrial sludge. This situation was confirmed by what was reported in several investigations using another kind of construction materials. Joshi [13] mentioned that the blocks with partial sand replacement in up to 10% by sludge meet the standard requirements.

Table 5. *Effect considering the interaction between the levels of both factors for tensile strength after Open Time*

Interaction	MUN-10%	MUN-20%	MUN-30%	IND-10%	IND-20%	IND-30%
Average (MPa)	0.15	0.34	0.12	0.03	0.02	0.31
Stand. deviation	0.04	0.05	0.02	0.01	0.00	0.01
Variance	0.00	0.00	0.00	0.00	0.00	0.00
Min	0.13	0.30	0.10	0.02	0.01	0.30
Max	0.19	0.39	0.13	0.04	0.02	0.32
CV	23.17%	14.72%	16.45%	26.78%	17.31%	2.62%

Table 6. *Effect considering the interaction between the levels of both factors for tensile strength after immersion in water*

Interaction	MUN-10%	MUN-20%	MUN-30%	IND-10%	IND-20%	IND-30%
Average (MPa)	0.19	0.05	0.07	0.34	0.26	0.24
Stand. deviation	0.04	0.01	0.01	0.07	0.11	0.04
Variance	0.00	0.00	0.00	0.01	0.01	0.00
Min	0.14	0.05	0.06	0.29	0.18	0.20
Max	0.23	0.07	0.08	0.42	0.39	0.28
CV	22.03%	18.87%	17.52%	21.17%	42.45%	15.99%

However, when higher percentages were tested, the quality of the material decreased. In the case of Pavlík [14], they reported that in the Portland cement production the safe limit for the practical use of domestic sludge as substituents of other raw materials was 10%, mainly due to the relatively high content of chlorides and alkalis. On the other hand, Tanpure [15] found that the sludge portion can vary between 10% to 50% of sludge by incorporating 12% of fly ash and that as the percentage of WWTP sludge in the mixture increases, so does the water absorption. It was also obtained that the compression resistance value decreased according to a higher percentage of sludge addition in the mixture

3.5. Tensile strength after open time and after immersion in water for the commercial glue

Tables 7 and 8 present the results for tensile strength after open time and after immersion in water for commercial glue. It was identified that, in both cases, the resistance is greater than that obtained when using the two sludge in the industrial glue, exceeding that recommended by the NTC 6040 standard (0.5 MPa). The variability was found to be low in both trials for the commercial glue. On the other hand, it is recommended to use the industrial sludge as a replacement for fine aggregate in the manufacture of floor glues, but in low proportions (<20%), since it was found that, by increasing the replacement of this material, the resistance to traction after immersion decreases.

Table 7. *Indicators for the Control Sludge on resistance response after Open Time*

Commercial	Indicator
Average (MPa)	0.54
Stand. Deviation	0.07
Variance	0.00
Min	0.48
Max	0.62
CV	12.43%

Table 8. *Indicators for the control sludge over the tensile strength response after immersion*

Commercial	Indicator
Average (MPa)	0.53
Stand. Deviation	0.10
Variance	0.01
Min	0.43
Max	0.62
CV	18.62%

4. Conclusions

The industrial sludge of the metalworking production sector (company 2, 3 and 4) had a higher content of substances that were not very reactive with cement such as feldspars and iron ores, and therefore had a significant potential to add them to the ceramic glue. Specifically, it was found that the industrial sludge of the company 2 of the metalworking sector has a potential to replace the aggregates of the ceramic glue, since greater tensile strengths were obtained, being the best behavior when replacing 10% of this sludge (0.34 MPa). It should be noted that when used in 20 and 30% resistance decreases, however, all values are acceptable. The industrial sludge as a replacement of fine aggregate in the manufacture of floor glues proved to be adequate, but in low proportions (<20%), since it was found that, when increasing this material, the tensile strength after immersion decreases. Finally, it was found that the most suitable sludge to replace a percentage of the conventional aggregates of the ceramic glue is that produced by the company 2 of the metalworking sector, since it presented acceptable values in both the open time resistances and after immersion in the water.

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