

# Comparative study of ideal and inadequate coarse aggregate on the mechanical properties of concrete

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**Abstract**— *The purpose of this study was to produce concrete with ideal coarse aggregate and compare it to concrete made with inadequate aggregate. Assess the influence of inappropriate aggregate on concrete properties. The concretes produced with Blade aggregate presented an elasticity module superior to the concrete with cubic aggregate, demonstrating greater elasticity in the concrete and, in the tensile strength, they presented better performance in the first ages. For fresh concrete and compressive strength, the cubic shape performed better. The cubical shape, considered ideal, has length/thickness <18 mm and width/thickness <18 mm; the blade shape, considered inadequate, has length/thickness >30 mm and width/thickness >30 mm. The physical properties of ideal coarse aggregate and inadequate aggregate were compared after separation and classification for concrete production and subsequent analysis of workability, compressive strength, tensile strength and modulus of elasticity of the resulting concrete. The goal was to assess the influence of ideal and inadequate coarse aggregate in different situations: dry material content, binder content, w/c ratio and concrete strength.*

**Keywords**— *Coarse aggregate; Ideal aggregate; Inadequate aggregate; Concrete performance.*

## I. INTRODUCTION

The study of aggregate shape for concrete asphalt and concrete hydraulic is an area already explored by researchers such as [1–3], who were the first to propose an aggregate shape classification method. Currently, there is a great amount of research on the classification of coarse aggregate shape for concrete, such as [4–10], and regulatory norms such as [11–16] that refer to the ideal coarse aggregate shape for concrete.

The crushing mechanism is one of the main factors that influences the characteristics of natural stone aggregate, such as particle size distribution, shape, texture, size, specific mass and unit mass. Crushers produce aggregates of various sizes and shapes that can perform positively or negatively in the production of concrete.

Aggregate shape affects concrete behavior, both in the fresh and hardened states, because it influences workability, internal friction angle and compactability, among other factors dependent on kneading water amount[9]. Cubical

aggregate presents better performance than those with elongated, discoid and laminar shapes [17].

According to studies done by [17,18], cubical aggregates are generally preferable to flat or elongated aggregate for use in concrete, since they have lower surface area per volume unit and normally lead to better aggregate packing. Laminar aggregates produce mixtures with low workability for a given amount of water, which leads to poor compaction and high void content, resulting in low resistance and durability.

Laminar aggregates, when compared to cubical aggregates, tend to break along the particle axis due to their slenderness. Thus, aggregate shape affects concrete strength and life span [19].

According to Isabel [20], the determination of the ratio between the largest and smallest size of the aggregate in her experimental results indicate that, when most particles have a ratio lower than 3:1, aggregate shape will have little influence on the quality of concrete. However, when more

than 50% of particles have a ratio of 5:1, concrete strength will be affected.

## II. METHODOLOGY

Aggregate shape refers to its three-dimensional geometry, but as it is difficult to represent irregular three-dimensional bodies, it is more convenient to define certain geometric characteristics of these bodies, such as elongation, flatness, cubicity, sphericity and angularity [6].

According to studies by [2,21–23], commonly employed methods to determine aggregate shape are based in the measuring of fragment dimensions through projection lines that define length, width and thickness.

Considering the ideal shape in the crushing process and exact dimensions (imagining a perfect shape), the shape of coarse aggregate can be classified according to its length/thickness and width/thickness ratios.

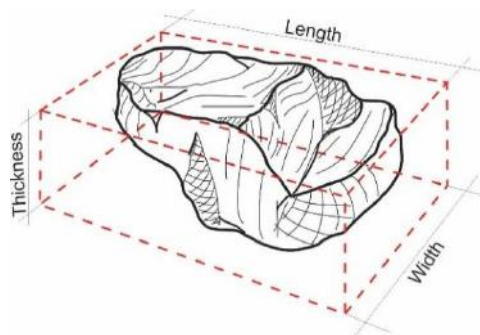


Fig.1: Projection of ideal particle shape over real particle shape

The method employed in this study was the one proposed by Silva and Geyer[10], which classifies aggregate shape in four categories (cubical, elongated, rod and blade), according to Table 1 for crushed natural coarse aggregate, having as reference the ratios of its dimensions. Aggregate shape is considered cubical for shape indices length/thickness and width/thickness  $< 1.8$ , elongated for length/thickness  $> 1.8$  and width/thickness  $< 1.8$ , rod for length/thickness  $> 2.4$  and width/thickness  $> 2.4$  and blade for length/thickness  $> 3.0$  and width/thickness  $> 3.0$ .

Table 1 Shape index determination[10]

Shape	Ratio	Index
Cubical	$l/t < \text{and } w/t <$	18 mm
Elongated	$l/t > \text{and } w/t <$	18 mm
Rod	$l/t > \text{and } w/t >$	24 mm
Blade	$l/t > \text{and } w/t >$	30 mm

For the analysis of a given aggregate, its axes are defined according to [11], in which the greatest dimension obtained is referred to as length; the intermediate dimension as width, and the smallest dimension as thickness. Classification of crushed coarse aggregate is derived from the degree of particle cubicity, and, according to Silva and Geyer [10], coarse aggregate shape can be classified as cubical, elongated, rod or blade.



Fig.2: Cubical shape



Fig.3: Elongated shape



Fig.4: Rod shape



Fig.5: Blade shape

According to the analysis in [9], aggregate of cubical shape is considered ideal, aggregates of elongated and rod shape are considered acceptable and aggregate of blade shape is considered inadequate for concrete production.

Table 2 Classification of aggregate shape as ideal, acceptable or inadequate for concrete

Shape	Parameter
Cubical	Ideal aggregate
Elongated	Acceptable aggregate
Rod	
Blade	Inadequate aggregate

Source: [9]adapted

Table 3 Coarse aggregate characterization

Test	Coarse aggregate	Norm
Fineness modulus	7.48	NBR NM 248 (ABNT, 2003)
Maximum characteristic size (mm)	25	NBR NM 248 (ABNT, 2003)
Unit mass (kg/dm <sup>3</sup> )	1.37	NBR 7251(ABNT, 1982)
Specific mass (kg/dm <sup>3</sup> )	2.67	NBR NM 53 (ABNT, 2003)

### III. EXPERIMENTAL PROGRAM

#### 3.1 Aggregate selection

The coarse aggregate selected for the experimental program was granulite from the Anápolis – Goiás quarry, due to its crushing process, rock origin and technical specifications, in line with [24]. This rock is of metamorphic origin and presents a high degree of metamorphism, granoblastic texture and gneissic structure, resembling granite (an igneous rock rich in quartz, feldspar and mica) due to its mineralogy and texture. Aggregate within an interval between 19 mm and 25 mm was used, which best fits the experiment due to its ease of handling.

#### 3.2 Extraction and crushing of coarse aggregate

Extraction of the rock is achieved by open pit blasting. Afterwards, it is transported by trucks over a distance of 500 m to the primary crusher (jaw crusher), and after the primary crushing, it is transported by conveyors to the secondary crusher (cone crusher). The rock is kept in the secondary crushing process until it acquires the desired particle size distribution. Then, it is transported by conveyors to the tertiary crusher (cone crusher) and, when the required grain size is obtained, it is transported by trucks to the end consumer.

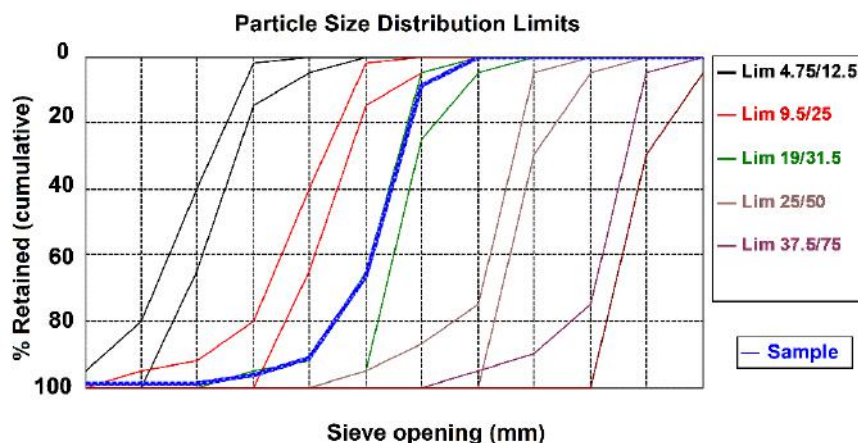
#### 3.3 Coarse aggregate analysis

The tests for characterization of particle size distribution, specific mass, unit mass and shape index of the coarse aggregate used in the experiment were done in the Laboratório de Materiais da Escola EEC/UFG (Materials Laboratory of the Civil Engineering School of the Federal University of Goiás), with the following results in regards to particle composition [25–27].

Table 4 Coarse aggregate particle size test

Opening Mesh size (mm)	Retained weight (g)	Test	
		Simple	Cumulative
75	0	0	0
63	0	0	0
50	0	0	0
37.5	0	0	0
31.5	0	0	0
25	870	9	9
19	5750	58	66
12.5	2500	25	91
9.5	500	5	96
6.3	284	3	99
4.75	0	0	99
2.36	0	0	99
Pan	96	1	100
TOTALS	10000	100	-

The coarse aggregate presented continuous particle size distribution within the acceptable limits for concrete production in line with technical specifications as determined by norm [25].



Graph 1 Coarse aggregate particle size test

### 3.4 Coarse aggregate shape classification

Ten samples of 10 kg of coarse aggregate each were prepared and the following sequence was observed: characterization, cataloging and sample separation.

Sample characterization was undertaken according to Table 1, followed by cataloging and separation of the aggregate between cubical, elongated, rod and blade shapes, according to [10].

Table 5 Characterization of Sample 1 (10 Kg)

Shape	Number of aggregates	Index	Weight (kg)	%
Cubical	331	15 mm	3,35	33,50%
Elongated	363	21 mm	3,11	31,10%
Rod	204	27 mm	1,61	16,10%
Blade	365	60 mm	1,93	19,30%
TOTAL	1.263 (aggregates)	32 mm	10,00	100,00%

Table 5 presents the classification and separation of the particles between cubical, elongated, rod and blade shapes, based on their dimensions and according to Table 1.

For the first analysis, classification was done according to shape, quantification and weighing of each particle and subsequent measuring of total weight for each shape, with

the goal of determining the exact representation of each shape in a 10 kg sample. From the second analysis onward individual weighing of particles was not undertaken.

Table 6 presents the result of aggregate analyses 1 through 5, and Table 7 presents the results of analyses 6 through 10. All analyses consisted of 10 kilograms of the selected aggregate.

Table 6 Comparison of coarse aggregate samples 1 through 5 according to shape

Shape	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
	Weight (kg)	Weight (kg)	Weight (kg)	Weight (kg)	Weight (kg)
Cubical	3,35	3,29	3,1	3,09	3,20
Elongated	3,11	3,19	3,21	3,19	3,21
Rod	1,61	1,70	1,95	1,79	1,65
Blade	1,93	1,81	1,72	1,93	1,94

Table 7 Comparison of coarse aggregate samples 6 through 10 according to shape

Shape	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
	Weight (kg)	Weight (kg)	Weight (kg)	Weight (kg)	Weight (kg)
Cubical	3,30	3,25	3,10	3,09	3,35
Elongated	3,12	3,03	3,25	3,50	3,14
Rod	1,80	1,76	1,69	1,55	1,80
Blade	1,78	1,96	1,96	1,86	1,71

#### IV. CONCRETE PRODUCTION

The chosen aggregates for concrete production were the one with cubical shape, considered ideal, with shape index length/thickness and width/thickness of 15 mm, and the one with blade shape, considered inadequate, with shape index length/thickness and width/thickness of 60 mm.

IPT's (Institute of Technological Research) dosing method was used for concrete production and subsequent analysis of mixes with respect to compressive strength of 10x20 cm specimens at 7, 14 and 28 days, diametral compressive strength of 10x20 cm specimens at 28 days, and modulus of elasticity of a 15x30 cm specimen at 28 days.

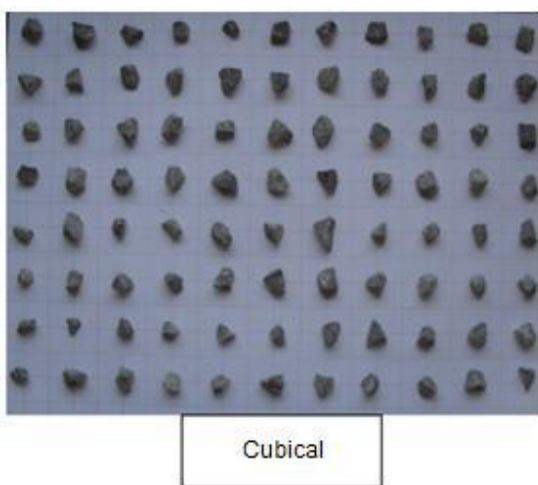


Fig.6: Images of particles according to their classification – cubical shape (Index 1,52:1)

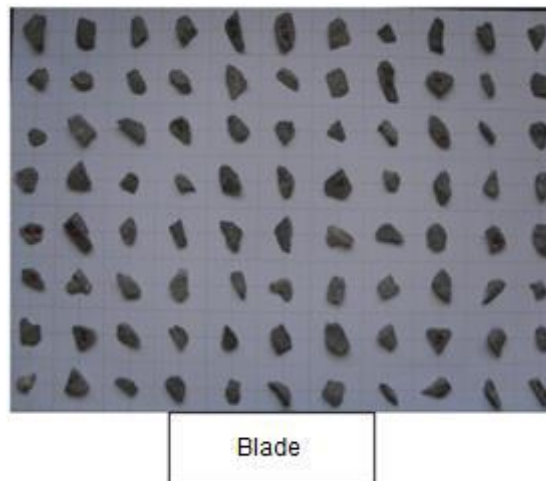


Fig.7: Images of particles according to their classification – blade shape (Index 6,7:1)4.1 Concrete dosing

Three different concrete mixes were produced for each aggregate shape: a 1:3,5 mix with high cement consumption, a 1:5 mix with moderate cement consumption, and a 1:6,5 mix with low cement consumption. The goal was to assess the influence of aggregate in different situations: dry material content, binder content, w/c ratio and concrete strength.

Mortar content for the cubical shape aggregate was determined in laboratory (alpha at 0,52). As aggregate shape index increases, so does the irregularity of coarse aggregate; thus, the value of alpha was changed in +0,03 for the blade shape (alpha at 0,55). This procedure was necessary to maintain the same finish in concrete with different aggregate irregularity indices. Table 8 Dry material amount – Cubical aggregate *mixes* and

Table 9 Dry material amount – Blade-shaped *aggregate mixes* present the dry material amounts for the cubical and blade-shaped aggregate mixes.



Table 8 Dry material amount – Cubical aggregate mixes

Mix	cement	coarse sand	gravel 1	Cement (kg/m <sup>3</sup> )
1:3,5	1	1,34	2,16	473,7
1:5	1	2,12	2,88	355,8
1:6,5	1	2,90	3,6	285,3

Table 9 Dry material amount – Blade-shaped aggregate mixes

Mix	cement	coarse sand	gravel 1	Cement (kg/m <sup>3</sup> )
1:3,5	1	1,47	2,025	464,0
1:5	1	2,30	2,70	348,8
1:6,5	1	3,12	3,37	274,9

Fresh concrete tests followed the standards of [28] for determination of consistency by slump test. Results of the conic frustum slump were obtained by dosing the concrete without additives. Only water was used to adjust the workability of the concrete, until it led to a slump of the conic frustum of  $10 \pm 2$  cm. Table 10 and Table 11 present the w/c ratio and slump test result for the cubical and blade shapes.

Table 10 w/c ratio and slump test – cubical shape

Mix	w/c	Slump test
1:3,5	0,426	10 cm
1:5	0,544	10 cm
1:6,5	0,657	9 cm

Table 11 w/c ratio and slump test – blade shape

Mix	w/c	Slump test
1:3,5	0,468	10 cm
1:5	0,598	10 cm
1:6,5	0,785	9 cm

## V. COMPRESSIVE STRENGTH RESULTS

To assess the compressive strength of the concrete, compression tests were done according to [29], in order to determine concrete performance at 7, 14 e 28 days of age of 10x20 cm cylindrical specimens. A sulfur surface capping was used in order to regularize the surface of the cylindrical specimen for breaking in the press. Table 12 and

Table 13 show the result of concrete compression with cubical and blade-shaped aggregate.

Table 12 Concrete compressive strength – cubical shape

Mix	7 days	14 days	28 days
1:3,5	26.04 MPa	31.71 MPa	36.35 MPa
1:5	21.46 MPa	25.41 MPa	26.23 MPa
1:6,5	15.09 MPa	17.38 MPa	18.72 MPa

Table 13 Concrete compressive strength – blade shape

Mix	7 days	14 days	28 days
1:3,5	25 MPa	26 MPa	31.2 MPa
1:5	15.8 MPa	17.7 MPa	20.1 MPa
1:6,5	9.1 MPa	11.1 MPa	16.9 MPa

## VI. TENSILE STRENGTH BY DIAMETRAL COMPRESSION RESULTS

Tensile strength by diametral compression tests of 10x20 cm cylindrical specimens at 28 days were undertaken according to the norm [30]. Table 14 Results of tensile strength by diametral compression tests at 28 days presents the response of the concrete to diametral compression at 28 days for the cubical and blade shapes.

Table 14 Results of tensile strength by diametral compression tests at 28 days

Mix	Cubical Shape	Blade Shape
1:3,5	12.5 MPa	12.9 MPa
1:5	10.9 MPa	9.5 MPa
1:6,5	8.0 MPa	5.9 MPa

## VII. MODULUS OF ELASTICITY RESULTS

Modulus of elasticity tests of cylindrical specimens at 28 days were done with respect to procedures established by the norm [31]. A sulfur surface capping was used in order to regularize the surface of the cylindrical specimen for breaking in the press. Table 15 and Table 16 present the modulus of elasticity results for cubical and blade shapes.

Table 15 Modulus of elasticity results for cubical shape

Mix	MPa	GPa
1:3,5	34.6	23.3
1:5	25.3	28.4
1:6,5	18.2	37.5

Table 16 Modulus of elasticity results for blade shape

Mix	MPa	GPa
1:3,5	27.6	19.7
1:5	19.6	32.8
1:6,5	12.2	44.3

Table 17 Particle size distribution results for cubical shape

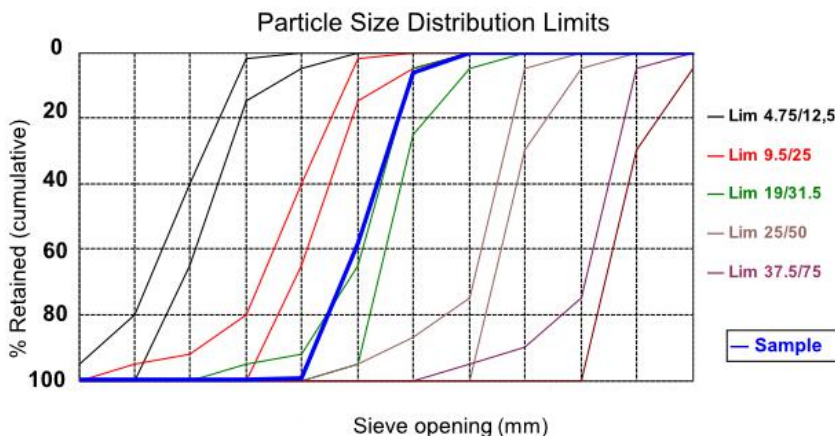
Opening Sieves (mm)	Weight retained (g)	Test	
		Simple	Cumulative
75	0	0	0
63	0	0	0
50	0	0	0
37.5	0	0	0
31.5	0	0	0
25	0	0	0
19	4456	45	45
12.5	5450	55	99
9.5	87	1	100
6.3	4	0	100
4.75	1	0	100
2.36	0	0	100
Pan	2	0	100
TOTALS	10000	100	-

### VIII. ANALYSES AND DISCUSSION OF RESULTS

#### 8.1 Analysis of cubical shape and blade shape aggregates

Based on the results, the smaller the particle size, the greater its irregularity. Therefore, for an aggregate with particle size between 19 mm and 25 mm to be classified as a good quality aggregate, with continuous and well graded particle size distribution, a certain quantity of particles of decreasing order is required in order to fit the ideal particle size distribution curve.

Table 17 and Graph 2 present the particle size distribution test results for cubical aggregate, which approached the ideal particle size distribution, with 99% of particles retained in sieves with openings of 25, 19, 12.5 and 9.5 mm.



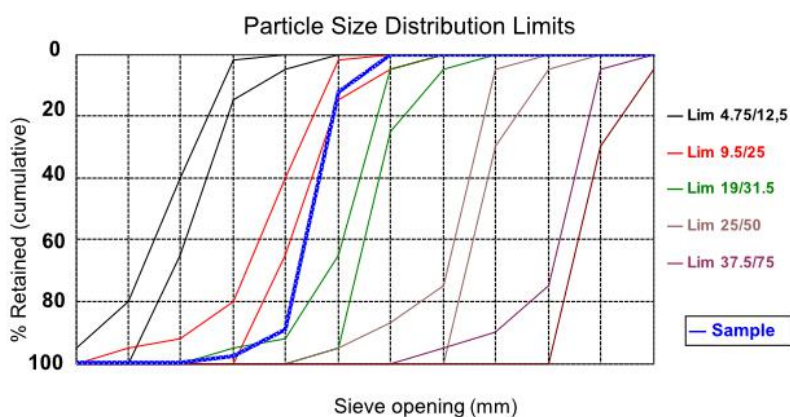
Graph 2 Cubical aggregate particle size distribution

Table 18 and Graph 3 present the particle size distribution test results for blade-shaped aggregate, which differed from the ideal particle size distribution, with 98% of

particles retained in sieves with openings of 19, 12.5 and 9.5 mm.

Table 18 Particle size distribution results for blade shape

Opening Sieves (mm)	Retained weight (g)	Test	
		Simple	Cumulative
75	0	0	0
63	0	0	0
50	0	0	0
37.5	0	0	0
31.5	0	0	0
25	0	0	0
19	1244	12	12
12.5	7654	77	89
9.5	879	9	98
6.3	200	2	100
4.75	12	0	100
2.36	3	0	100
Pan	8	0	100
TOTALS	10000	100	-



Graph 3 Blade-shaped aggregate particle size distribution

Table 19 Characterization results of cubical and blade shapes presents the test results for cubical and blade-shaped aggregates used for concrete production.

Table 19 Characterization results of cubical and blade shapes

Test	Cubical	Blade	Norm
Fineness modulus	7,58	7,10	NBR NM 248 (ABNT, 2003)
Maximum characteristic size (mm)	25	25	NBR NM 248 (ABNT, 2003)
Unit mass (kg/dm <sup>3</sup> )	1,413	1,279	NBR 7251(ABNT, 1982)
Specific mass (kg/dm <sup>3</sup> )	2,57	2,72	NBR NM 53 (ABNT, 2003)
Aggregate shape index (mm)	15	60	NBR 7809(ABNT, 2008)

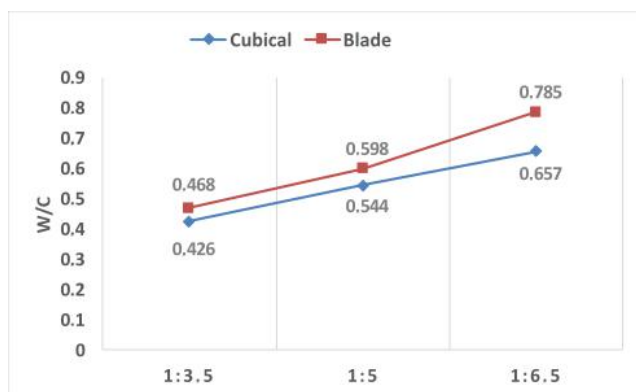


It can be observed that the crushing process significantly influences the physical properties of the crushed aggregate, such as specific mass, unit mass, fineness module and shape index.

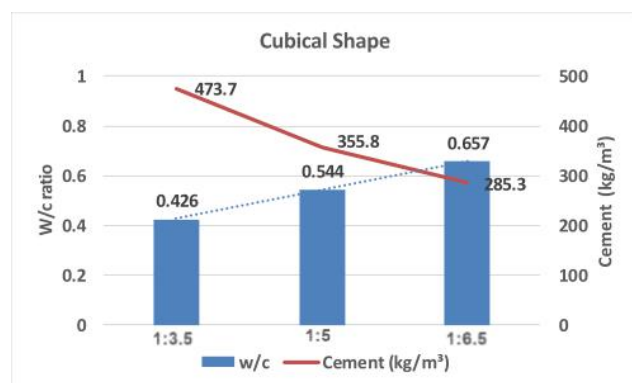
It is important to note that coarse aggregates with blade shape or inadequate particle size distribution do not fit the dosing methods, which are based, for instance, on ideal particle size distribution curves, and influence the properties of concrete and its cement consumption [7].

### 8.2 Fresh concrete

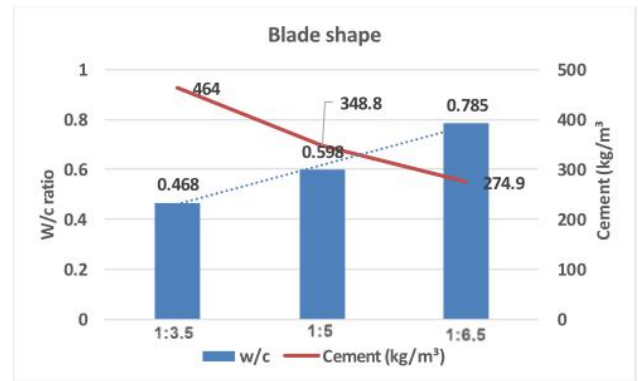
As the amount of mortar in a mix increases, it is necessary to increase the water/binder ratio in order to maintain the same workability. Concrete with blade-shaped aggregate presented higher water consumption when compared to concrete with cubical aggregate, to maintain the desired workability. Graph 4, Graph 5 and Graph 6 present the w/c ratio of concrete mixes produced with cubical and blade-shaped aggregates.



Graph 4 W/c ratios for cubical and blade shapes



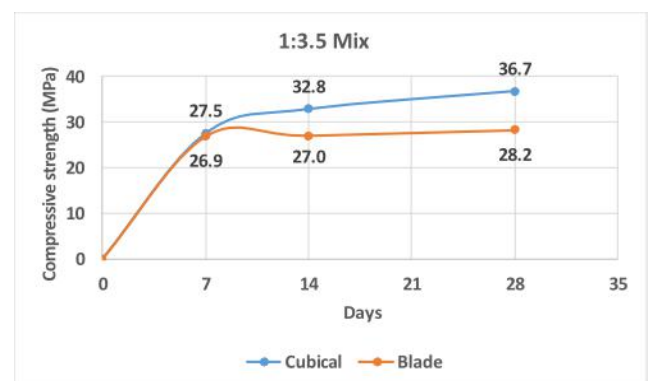
Graph 5 W/c ratios for cubical shape



Graph 6 W/c ratios for blade shape

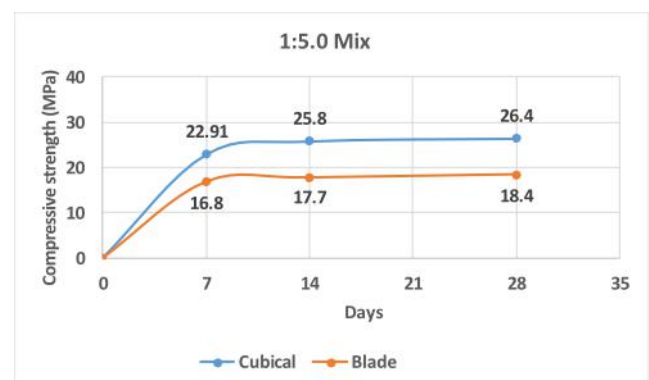
### 8.3 Compressive strength

Concretes with ideal (cubical) shape used for the experimental program have 100% of particles with an average ratio of 1.5:1. Concretes with inadequate (blade) shape, in contrast, have 100% of particles with an average ratio of 6:1. Graph 7, Graph 8 and Graph 9 present the compressive strength results for the 1:3.5, 1:5 and 1:6.5 mixes.

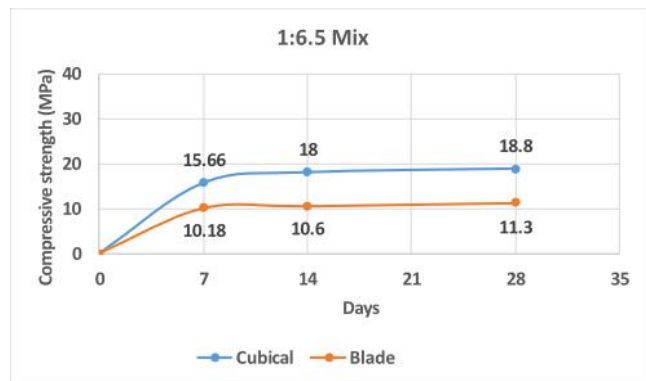


Graph 7 Compressive strength results of the 1:3.5 mixes

Compressive strength results of the 1:3.5 mix with cubical aggregate showed the best results for all ages, and a better strength projection when compared to the concrete with inadequate (blade-shaped) aggregate.



Graph 8 Compressive strength results of the 1:5 mixes



Graph 9 Compressive strength results of the 1:6,5 mixes

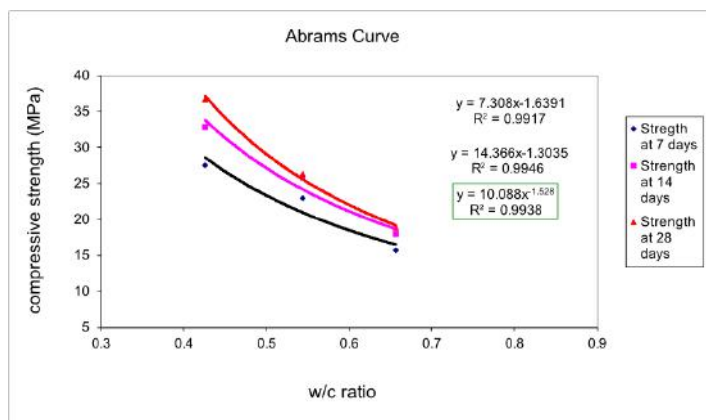
The 1:5 and 1:6,5 mixes with ideal (cubical) aggregate showed the best results for all ages. However, both aggregate shapes presented a similar strength projection.

The 1:3,5 mix with cubical aggregate presented an increase in strength, from 7 to 28 days of age, of 9.2 MPa, followed

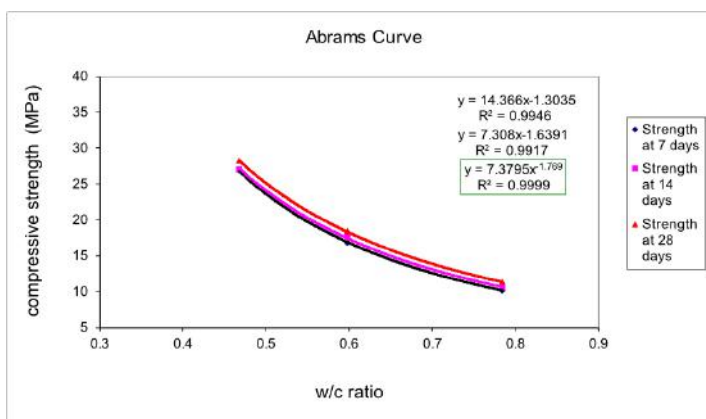
by the 1:5 mix with an increase of 3.49 MPa and the 1:6,5 mix with the smallest increase of 3.14 MPa. For the compressive strength of blade-shaped aggregate concrete, the 1:5 mix showed an increase in strength, from 7 to 28 days of age, of 1.6 MPa, followed by the 1:3,5 mix with an increase of 1.34 MPa and the 1:6,5 mix with the smallest increase of 1.12 MPa.

Compressive strength of ideally shaped (cubical) aggregate presented better performance due to the compaction index of the aggregate, which, in general, has continuous particle size distribution, thus favoring the concrete and making it denser and less porous.

Graph 10 and Graph 11 present the Abrams curve for w/c ratio of the 1:3,5, 1:5 and 1:6,5 mixes at 7, 14 and 28 days old, for cubical and blade-shaped aggregates.



Graph 10 W/c ratio and compressive strength at 3, 7 and 28 days (cubical shape)



Graph 11 W/c ratio and compressive strength at 3, 7 and 28 days (blade shape)

Cubical aggregate presents better characteristics for use in concrete when compared to blade-shaped aggregate. Cubical aggregate is denser, stronger and shows better performance than inadequate aggregates, making the mortar more fragile than the aggregate, and, due to these properties, fractures or cracks start in the transition zone between mortar and aggregate when the concrete is submitted to stress. The inadequate aggregate shape is highly flat, causing a build-up of voids in the concrete microstructure, making it fragile and brittle, ultimately weakening its microstructure.

Studies done by [32] indicate that the influence of aggregate properties on workability and mechanical strength decreases with the increase of cement amount, and according to studies proposed by [9], which consider cubical aggregate as ideal coarse aggregate and blade-shaped aggregate as inadequate for concrete production, and its influence on the mechanical properties of concrete, there is a loss of concrete properties with the increase of inadequate aggregate amount. However, some researchers

such as [20] suggest that concrete strength is affected if more than 50% of the aggregate has a 5:1 shape index (blade shape), which can lead to low compaction and high void rate, resulting in low strength and lower durability concrete. [9], in contrast, reports that a proportion higher than 20% of inadequate (blade-shaped) aggregate affects concrete performance with respect to compressive strength, tensile strength and modulus of elasticity.

### 8.3 Tensile strength by diametral compression

For the tensile strength by diametral compression tests, the 1:3,5 concrete mix with inadequate (blade) shape aggregate showed better performance than the concrete with ideal (cubical) aggregate. However, there was a sharper decrease in the concrete with inadequate (blade) shape for mixes with lower cement amount. Concrete with ideal (cubical) aggregate presented better performance for mixes with moderate (1:5) and low (1:3,5) cement consumption. Graph 12 and Graph 13 present the tensile strength test results for the 1:3,5, 1:5 and 1:6,5 mixes.

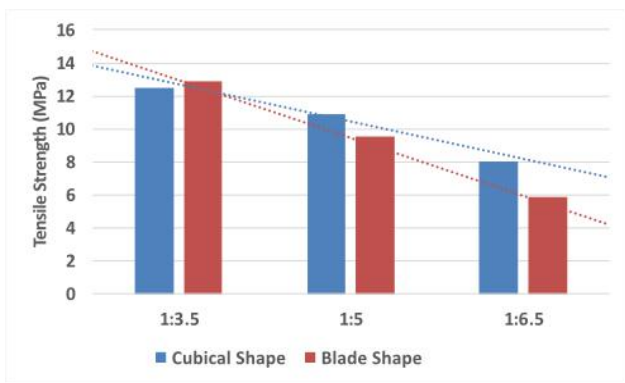
The negative influence of the physical characteristics of inadequate aggregate is greater than that of the cement. The inadequate particle's shape is fragile and when submitted to stress it tends to rupture as a fixed beam, making the coarse aggregate the weak point of the concrete microstructure.

With respect to tensile strength by diametral compression, the concrete made with inadequate aggregate showed the best performance, with an Fck of 12.86 MPa for the 1:3,5 mix. This result can be attributed to the greater surface area of inadequate aggregate, which leads to higher adherence between the aggregate and the mortar.

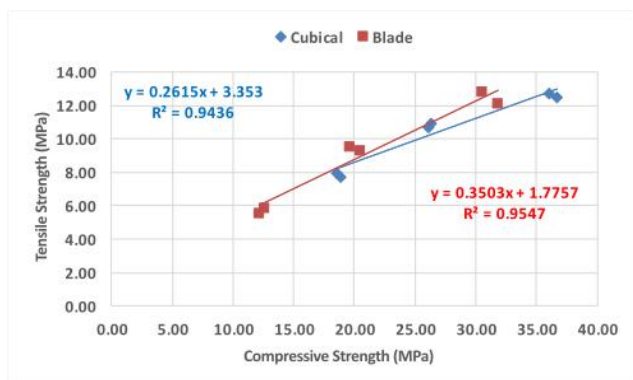
Due to the greater surface area of the inadequate (blade-shaped) aggregate, a better contact region between mortar and coarse aggregate is achieved. Inadequate aggregates, for being slimmer and flatter, function as anchoring areas in the microstructure of concrete when submitted to stress. This effect occurs in mixes with high cement consumption.

### 8.4 Elasticity modulus

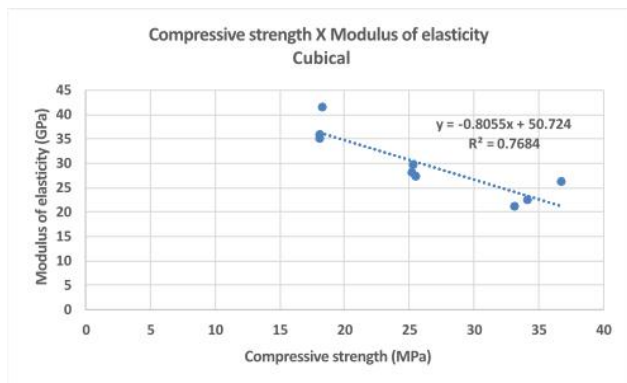
For the concrete made with cubical and blade-shaped aggregates, it was observed that with the increase of w/c ratio there was an increase in the concretes' modulus of elasticity and a decrease in the compressive strength. Graph 14 and Graph 15 show that a higher w/c ratio results in a lower compressive strength and a higher modulus of elasticity. This is attributed to the high amount of pores caused by high water consumption in the concretes.



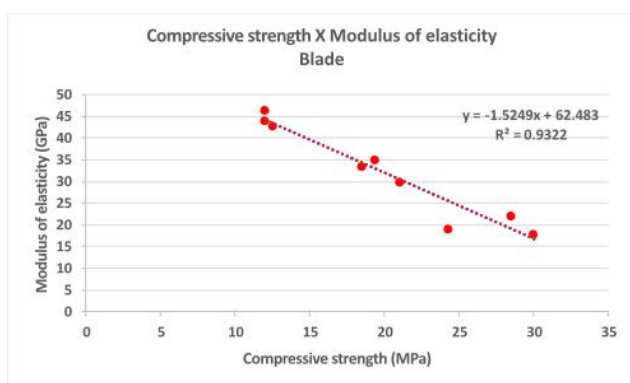
Graph 12 Tensile strength results at 28 days



Graph 13 Relationship between tensile strength and compressive strength at 28 days for cubical and blade shapes

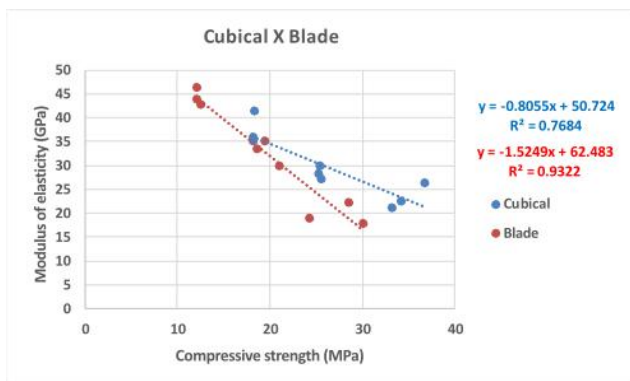


Graph 14 Relationship between compressive strength and modulus of elasticity at 28 days (cubical shape)



Graph 15 Relationship between compressive strength and modulus of elasticity at 28 days (blade shape)

Concrete with a high rate of voids in its microstructure can suffer elastic deformations, causing microdeformations in its interior. By using the pore network in the concrete microstructure, it can settle before rupturing. Graph 16 compares the modulus of elasticity of the cubical aggregate concrete and the blade-shaped aggregate concrete at 28 days.



Graph 16 Comparison of the modulus of elasticity of cubical and blade shapes at 28 days

The 1:3,5 mix with cubical aggregate was determined to have a higher modulus of elasticity than the one with blade-shaped aggregate. This result can be attributed to the high cement consumption along with the good performance of the ideal shape, which produces a denser and more compact concrete, allowing it to reach high strengths before rupturing. For the remaining mixes, with moderate and low cement consumption, the concrete with blade-shaped aggregate presented lower compressive strength and higher modulus of elasticity when compared to that with cubical aggregate. According to studies performed by [33–35], this result is due to the influence of inadequate aggregate on the mechanical properties of concrete, such as the increase of porosity that causes greater elastic deformation before the rupture of concrete at low strengths.

### IX. CONCLUSION

According to analysis of the concrete, the ideal aggregate with cubical shape has better performance when compared to the blade shape in concrete production, due to aggregate shape and good particle size distribution, which allows good packing of coarse and fine aggregates, eliminating voids in the microstructure of the concrete and improving the properties of both fresh and hardened concrete.

Concrete produced with inadequate aggregate with blade shape produces higher void rates caused by the accumulation of bubbles. These voids provide elasticity to the concrete, functioning as tension concentrators and allowing the concrete to work when subjected to stress. However, it makes the concrete more fragile, causing it to rupture at low resistance.

With data from monitored tests of traction, compression and modulus of elasticity, where there is a record of the deformations presented for each trace of the elongated-lamellar shape. The behavior stops being linear just before the last load. This behavior is due to the progressive micro cracking that occurs initially at the coarse aggregate interface and the cement paste, and subsequently spreads throughout the concrete, presenting greater elastic deformations before rupture, in contrast to the cubic shape that presents few elastic deformations before rupture of concrete.

### REFERENCES

- [1] H. Wadell, Volume, Shape, and Roundness of Rock Particles, J. Geol. 40 (1932) 443–451. doi:10.1086/623964.
- [2] W. C. Krumbein, Measurement and Geological Significance of Shape and Roundness of Sedimentary Particles, SEPM J. Sediment. Res. Vol. 11 (1941) 64–72. doi:10.1306/d42690f3-2b26-11d7-8648000102c1865d.



- [3] M. C. Powers, A New Roundness Scale for Sedimentary Particles, *SEPM J. Sediment. Res.* Vol. 23 (1953) 117–119. doi:10.1306/D4269567-2B26-11D7-8648000102C1865D.
- [4] D. W. Fowler, Determination of aggregate shape properties using x-ray tomographic methods and the effect of shape on concrete rheology, The University of Texas at Austin, 2005. doi:10.15781/T2SG01.
- [5] F. Fabro, G. Gava, H. Grigoli, Influence of fine aggregates particle shape in concrete performance, *Rev. IBRACON Estruturas e Mater.* 4 (2011) 191–212.
- [6] M.F. NUNES, E.P. MARQUES, Agregados para a construção civil: Materiais de construção civil e princípios da ciência e eng. de materiais, in: 2007: pp. 481–524.
- [7] V.A. O'REILLY, Método de dosagem de concreto de elevado desempenho., in: L.T.S. e N.D.B. Tradução: Avelino A. de Pádua (Ed.), Pini, 1998, São Paulo - SP, 1998.
- [8] E.B. FRAZÃO, Tecnologia para produção e utilização de agregados: Agregados para Construção Civil no Brasil, (2007).
- [9] D. de A. e Silva, Estudo da Influência do Índice de Forma do Graúdo nas Propriedades Mecânicas do Concreto, Dissertação de (Mestrado) - Universidade Federal de Goiás, Escola de Engenharia Civil, 2012. doi:10.13140/RG.2.2.34443.13608.
- [10] D. de A. Silva, L.B. Geyer, Análise e classificação da forma do agregado graúdo britado para concreto, *Rev. Científica Multidiscip. Núcleo Do Conhecimento.* 05 (2018) 18–28. <https://www.nucleodoconhecimento.com.br/engenharia-civil/agregado-graudo>.
- [11] ABNT, Agregado graúdo - Determinação do índice de forma pelo método do paquímetro - Método de ensaio - NBR 7809, Abnt. (2008) 3.
- [12] DIN EN 933-3, Tests for geometrical properties of aggregates - Part 3: Determination of particle shape - Flakiness index, (1997) 13.
- [13] DIN EN 933-4, Tests for geometrical properties of aggregates - Part 4: Determination of particle shape - Shape index, (1999) 13.
- [14] ACI Committee 213R-87, Guide for Structural Lightweight Aggregate Concrete -, 87 (1999) 1–27.
- [15] BS 812-105.1, Testing aggregates: Methods for determination of particle shape - Flakiness index, (1989) 9. <http://saliergeotechnical.co.uk/British Standards NEW/BS EN 812/BS 812-105.1 1989.pdf>.
- [16] BS 812-105.2, Testing aggregates — Part 105: Methods for determination of particle shape — Section 105.2 Elongation index of coarse aggregate, (1990).
- [17] R. Petersen, R. Link, J.-S. Chen, M.-S. Shiah, H.-J. Chen, Quantification of Coarse Aggregate Shape and Its Effect on Engineering Properties of Hot-Mix Asphalt Mixtures, *J. Test. Eval.* 29 (2001) 513. doi:10.1520/JTE12396J.
- [18] D. Petersen, R. Link, C. Rao, E. Tutumluer, J. Stefanski, Coarse Aggregate Shape and Size Properties Using a New Image Analyzer, *J. Test. Eval.* 29 (2001) 461. doi:10.1520/JTE12276J.
- [19] J.M.R. Fernlund, Image analysis method for determining 3-D shape of coarse aggregate, *Cem. Concr. Res.* 35 (2005) 1629–1637. doi:10.1016/j.cemconres.2004.11.017.
- [20] F. ISABEL, M, G, Caracterização petrográfica, química e física de agregados graníticos em concreto: estudo de caso de obra., Faculdade de Ciência da Universidade de Porto, 2005.
- [21] A.B. PARAGUASSU, E.B. FRAZÃO, Materiais Rochosos para Construção, *Assoc. Bras. Geol. Eng. Ambient.* Único (1998) 331-342.
- [22] T. Al-Rousan, E. Masad, E. Tutumluer, T. Pan, Evaluation of image analysis techniques for quantifying aggregate shape characteristics, *Constr. Build. Mater.* 21 (2007) 978–990. doi:10.1016/j.conbuildmat.2006.03.005.
- [23] A. Ueno, Y. Ogawa, Influence of coarse aggregate shape on optimum fine to total aggregate ratio using a virtual voids-ratio diagram in concrete compaction, *Cem. Concr. Compos.* 106 (2020). doi:10.1016/j.cemconcomp.2019.103463.
- [24] ABNT, Agregados para concreto - Especificação - ANBT 7211, (2005) 15. [www.abnt.org.br](http://www.abnt.org.br).
- [25] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, Agregados - Determinação da composição granulométrica - NBR NM 248, (2003) 6.
- [26] NBR ABNT 7251, Agregado em estado solto - Determinação da massa unitária -, (1982) 3.
- [27] ABNT NM 53, Agregado graúdo – Determinação de massa específica, massa específica aparente e absorção de água - ABNT NM 53, (2003). [http://professor.pucgoias.edu.br/SiteDocente/admin/arquivo\\_sUpload/17827/material/Nbr\\_nm53\\_2003.pdf](http://professor.pucgoias.edu.br/SiteDocente/admin/arquivo_sUpload/17827/material/Nbr_nm53_2003.pdf).
- [28] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, Concreto - Determinação da consistência pelo abatimento do tronco de cone - NBR NM 67, (1998) 8.
- [29] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, Concreto - Ensaios de compressão de corpos-de-prova cilíndricos - NBR 5739, (2007) 14. doi:01.080.10; 13.220.99.
- [30] ABNT, NBR 7222 - Argamassa e concreto - Determinação da resistência à tração por compressão diametral de corpos-de-prova cilíndricos (Mortar and concrete - Determination of the tensile strength of cylindrical specimens subjected to diametrical compression) [in P, *Assoc. Bras. Normas Técnicas.* (2011) 4–6. doi:10.1109/TPWRS.2002.1007926.
- [31] ABNT, Concreto - Determinação do módulo estático de elasticidade à compressão - NBR 8522, ABNT- Assoc. Bras. Normas Tec. Rio Janeiro. (2008) 16.
- [32] S.S. Jamkar, C.B.K. Rao, Index of Aggregate Particle Shape and Texture of coarse aggregate as a parameter for concrete mix proportioning, *Cem. Concr. Res.* 34 (2004) 2021–2027. doi:10.1016/j.cemconres.2004.03.010.
- [33] D. de A. e Silva, A. L. B. Geyer, and J. da C. Pantoja, Estudo da forma do agregado graúdo e sua influência no módulo de elasticidade do concreto, *Brazilian J. Dev.*, vol. 06, no. 08, pp. 60426–60440, 2020, doi: 10.34117/bjdv6n8-453.
- [34] D. de A. e Silva, A. L. B. Geyer, and J. da C. Pantoja, Porosidade do concreto versus forma do agregado graúdo, *Brazilian J. Dev.*, vol. 06, no. 08, pp. 60359–30376, 2020, doi: 10.34117/bjdv6n8-449.
- [35] D. de A. e Silva, A. L. B. Geyer, and G. de S. Fernandes,



CAPÍTULO 8 - ESTUDO DA FORMA DO AGREGADO GRAÚDO E SUA INFLUÊNCIA NO MÓDULO DE ELASTICIDADE DO CONCRETO, in *Força, crescimento e qualidade da engenharia civil no Brasi*, Editora At., no. 17, Organizadora Franciele Braga Machado Tullio, Ed. Ponta Grossa, PR, 2020, pp. 92–115.