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PLASTIC WASTE FOR CONCRETE MIXTURE: ADVANCED STRATEGIES AND SOLUTIONS

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ABSTRACT

In recent years, various waste recycling strategies have emerged emphasizing the utilization of plastic waste in concrete mixtures. This practice offers a dual advantage by decreasing the demand for traditional aggregates, like sand and gravel, or lightweight aggregates while mitigating plastic accumulation in landfills and oceans, promoting a circular economy. Although high plastic content may worsen mechanical characteristics, proper mix designs can optimize concrete containing plastic aggregates to be lighter and beneficial for weight-sensitive applications.

This study investigates the influence of plastic waste on concrete mechanical characteristics, incorporating different types of plastic waste in varying percentages to identify potential applications. Experimental results indicate that incorporating plastic waste does not significantly compromise concrete strength. Despite promising findings, challenges associated with using plastic waste in concrete must be addressed to optimize this practice and overcome drawbacks. These efforts align with sustainable waste management and eco-friendly construction practices, underscoring the importance of refining the use of plastic waste in concrete.

Keywords: *Concrete, Waste Recycling, Plastic, Mechanical Performance.*

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1. INTRODUCTION

In recent years, waste management has become a topic of increasing importance, particularly about implementing innovative strategies aimed at mitigating environmental impact and, consequently, safeguarding human health from potential threats.

Plastic, a material found in almost every sector, offers indispensable utility. However, the exponential proliferation of plastic usage has originated an environmental crisis due to its non-biodegradable nature and extended degradation period, which exceeds 400 years. The accumulation of plastic waste poses multifaceted environmental risks, from occupying vast landfill spaces to threatening marine habitats and ecosystems, making the lifecycle of waste plastic inherently unsustainable.

Of the vast quantities of solid waste produced globally each year, approximately 6.5 million tons are represented by plastic waste [1], underscoring the substantial role played by plastics in this global issue. Moreover, as observed by numerous studies in the literature [2-3], the degradation processes release nanoparticles that contaminate the food chain, heavily affecting the marine environment and potentially compromising human health [4-6].

In this context, innovative solutions are fundamental to address the growing environmental and social consequences of plastic waste accumulation. Currently, general waste management practices often involve incineration [7], recycling [8] or landfilling, with the latter being the most commonly adopted method. However, there has been a recent emergence of intensified research into recycling strategies aligned with the principles of the Circular Economy.

Among them, novel recycling strategies, especially within the construction sector, have emerged as effective solutions. In particular, the potential of utilizing concrete for plastic waste management is gaining confidence [9-13].

This study discusses a strategy for the reuse of plastics consisting of incorporating it into concrete plastic waste, which otherwise ends up in landfills, reducing environmental degradation. To evaluate the effectiveness of this recycling strategy, experimental campaign results are reported and discussed, particularly focusing on the influence of varying sizes and percentages of plastic waste in concrete.

2. USE OF PLASTIC WASTE IN CONCRETE

Plastic waste can be considered a valuable resource in concrete production, providing environmental advantages and improving concrete performance. However, it is crucial to carefully select the type and amount of plastic additives to achieve optimal concrete properties and maintain construction sustainability. In recent years, numerous studies [9] have been

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conducted on this topic, driven by the pressing need to explore sustainable solutions to face the escalating production and disposal of plastic waste. These studies suggest that incorporating plastic waste into concrete can positively or negatively influence its mechanical performance, depending on the type and quantities of plastic used. Replacing fine aggregates, such as sand, with plastic can affect concrete properties, including compressive strength.

Tota-Maharaj et al. [10] investigated the use of waste plastic as a fine aggregate replacement in medium-strength reinforced concrete pavements, focusing on its impact on strength performance. For the scope, the influence of various weight fractions of fine plastic aggregates, ranging from 5% to 15% into concrete was investigated.

Adding plastic aggregates reduces concrete workability and compressive strength as the plastic percentage increases. This reduction in strength is attributed to the low bonding properties of plastic, resulting in weaker bonds between plastic particulates, aggregates and the cement paste [14]. While up to 10% of sand can be replaced without affecting strength [15], other studies [16] indicate a significant decrease in mechanical properties beyond 15% of plastic replacement.

Almeshal et al. [17] conducted a study investigating the effects of integrating Polyethylene Terephthalate (PET) as a partial substitute for sand in concrete mixtures. The study examined the physical and mechanical properties of concrete with varying levels of PET substitution, ranging from 0% to 50%. The results provided a decrease both in workability and compressive strength with higher PET replacement levels. In particular, for percentages of 10%, 20%, 30%, 40% and 50% of PET in concrete mixes, the compressive strength decreased by 1.2%, 4.2%, 31%, 60% and 90.6%, respectively. Additionally, they evaluated the fire resistance of the concrete, exposing specimens to a direct flame for 300 seconds. Tests showed that mixes containing PET exhibited high combustibility, with cracks appearing on exposed surfaces and emission of malodorous toxic white smoke at 30% and higher PET replacement ratios.

As discussed in the study of Almohana et al. [12], recycling plastic waste for use in concrete production presents several advantages, besides reducing environmental impact. In particular, plastic in concrete allows for improved thermal and sound insulation properties [18,19] and cost-effectiveness compared to traditional concrete. Moreover, plastic waste, being lightweight and readily available, offers a valuable alternative to conventional aggregates, with the capability to significantly enhance the efficiency of lightweight concrete insulation. By substituting a portion of the total aggregate with plastic waste (ranging from 50% to 75%), the efficiency of thermal and sound insulation in lightweight concrete can be substantially increased. In terms of economic considerations, utilizing plastic aggregates in concrete production represents a valuable and cost-effective solution. Studies suggest that replacing a fraction of sand with recycled plastic can save millions of tons of sand annually, contributing



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to resource conservation and reducing fuel consumption and carbon emissions associated with raw material extraction.

In this framework, an experimental investigation is here discussed providing data that adds to that available in the literature, useful to improve the level of knowledge for effective approaches in the including of plastic waste in concrete mixes.

3. EXPERIMENTAL INVESTIGATION

In this study, the mechanical properties of concrete incorporating three types of plastic aggregates are investigated and discussed, observing the influence of varying percentages in the mix. Compressive tests were conducted on concrete cubes with side of 150 mm, according to standards UNI EN 12390-4:2002 [20] and UNI EN 12390-3:2009 [21] after 7, 14 and 28 days of curing. Two concrete strength classes are considered: one with relatively low strength (20 MPa), referred to as class "C1", and the other with higher strength (40 MPa), referred to as class "C2". In concrete mix C1, two types of plastic aggregates were added to the control mix: light blue flakes (referred to as P1) were added in percentages of 10%, 20%, and 30%, and plastic flakes (referred to as P2) were added in percentages of 10% and 20%. In concrete mix C2, light blue flakes (P1) were added in percentages of 2%, 4%, 6%, and 30%, while plastic granules were added in percentages of 10%, 20%, and 30%. Specimen groups were named using the following notation: XX_YY_n, where XX indicates the concrete strength class (C1 for medium low concrete strength and C2 for medium high concrete strength), YY indicates the type of plastic aggregates (P1 for light blue flakes, P2 for plastic flakes, and P3 for plastic granules), and n indicates the percentage of plastic aggregates. Table 1 summarizes all the specimen groups while Table 2 provides the reference mix produced using Portland cement type 32.5 R, 20 mm crushed rock coarse aggregate and fine aggregate with 2 mm nominal maximum size.

3.1. Materials

In the present experimental campaign, three types of plastic aggregates were considered: light blue flakes (P1), flakes (P2), and granules (P3). These differ in terms of size and composition. Light blue flakes (P1), in Figure 1a, were obtained by grinding recycled washed plastics consisting mainly of Polyethylene Terephthalate (PET), Polypropylene (PP), and Polyvinyl Chloride (PVC). This type of plastic aggregate has a maximum dimension of <2 mm and a bulk density of 610 kg/m³. Plastic flakes (P2), in Figure 1b, were obtained by shredding different types of plastic bottles without washing, including Polyethylene (PE), PET, and PVC. The dimensions were <20 mm, with a bulk density of 400 kg/m³. Finally, plastic granules (P3), in Figure 1c, were obtained through grinding, washing, fusion, and extrusion of recycled PE and PP. These were characterized by a maximum dimension 10 mm and a bulk density of 580 kg/m³.

Table 1. Experimental programme (material characteristics).

Plastic aggregates			Sample group	
Type	Maximum dimension [mm]	Bulk densities [kg/m ³]	C1 - concrete with medium low strength (20 MPa)	C2 - concrete with medium high strength (40 MPa)
Light blue flakes (P1)	< 2	610	C1_P1_10% C1_P1_20% C1_P1_30%	C2_P1_2% C2_P1_4% C2_P1_6% C2_P1_30%
Flakes (P2)	< 20	400	C1_P2_10% C1_P2_20%	-
Granules (P3)	< 10	580	-	C2_P3_10% C2_P3_20% C2_P3_30%

Table 2. Reference mix

Quantity per cube meter [kg]	
Cement	330.7
Water	198.5
Fine aggregate	837.9
Coarse aggregate	771.7



Figure 1. Plastic aggregates: a) light blue flakes; b) flakes; c) granules.

4. EXPERIMENTAL RESULTS

The experimental results for cube compressive strength as a function of the percentage of plastic aggregates are presented in Figures 2a and 2b for low concrete strength (C1) with light blue plastic flakes (P1) and plastic flakes (P2), respectively. While, the results for high concrete strength (C2) with light blue plastic flakes (P2) and plastic granules (P3) are shown in Figures

3a and 3b, respectively. The results validate the expected trend, showing that compressive strength increases with longer curing time (from 7 to 28 curing days) and decreases with higher percentages of added plastic in the concrete mixes.

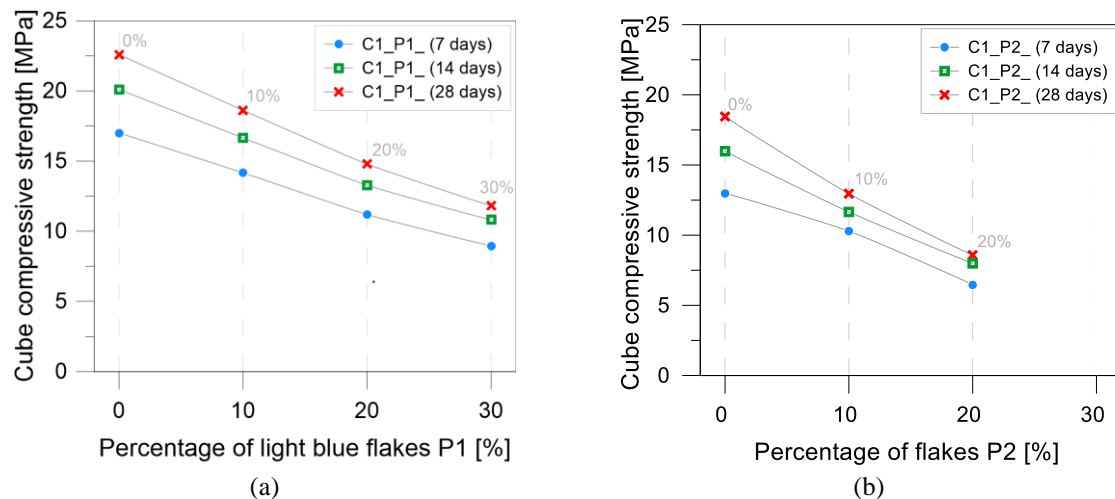


Figure 2. Cube compressive strength vs. percentage of plastic aggregates for samples C1 at different concrete ages (7, 14 and 28 days): a) with light blue plastic flakes (P1); b) with plastic flakes (P2).

The experimental results are summarized in Table 3, including the normalized compressive strength values. These normalized values are calculated by dividing the compressive strength of concrete mixes with plastic aggregates by that of the reference concrete mix.

Overall, for plastic aggregate percentages equal to or less than 10%, the decrease in strength is relatively minor, typically less than 20%, except for specimens containing plastic flakes aggregates (C1_P2_10%). However, when the percentage of plastic aggregates reaches 20%, the strength reduction is notably higher, almost 35% and 33% for mixes containing plastic light blue flakes (C1_P1_20%) and plastic granules (C2_P3_20%), respectively. Conversely, a significantly greater reduction, approximately 54%, is observed when the 20% of plastic flakes are added to the concrete mix (C1_P2_20%). From Figure 4, it is worth to observe that adding raw plastic flakes in concrete mix significantly reduces its compressive strength, with a decrease of up to 50% observed even at a 20% aggregate percentage. In contrast, plastic light blue flakes demonstrate better behaviour to this strength reduction.

The results obtained with plastic light blue flakes have been compared with some results in the literature. Because it is difficult to find an experimental campaign using the same reference mix, the comparison has been made referring to the amount of plastic mass in the mix, normalizing the strength with respect to the value provided by the reference mix. Fig. 5 shows these results highlighting how much different may be the results and the high variability of the

mix performance.

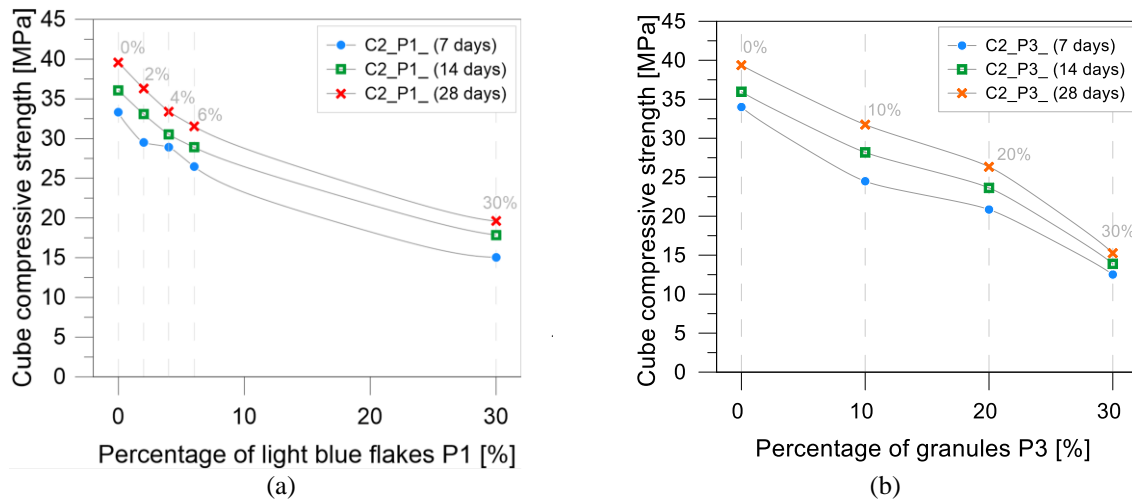


Figure 3. Cube compressive strength vs. percentage of plastic aggregates for samples C2 at different concrete ages (7, 14 and 28 days): a) with light blue plastic flakes (P1); b) with plastic granules (P3).

Table 3. Experimental results from compressive tests on cubes.

Concrete mix	Type and percentage (by total volume) of plastic aggregates	Compressive strength [MPa]			Normalized dimensionless compressive strength		
		7 days	14 days	28 days	7 days	14 days	28 days
C1	ref P1_0%	17.0	20.1	22.6			
	P1_10%	14.2	16.7	18.6	0.83	0.83	0.82
	P1_20%	11.2	13.3	14.8	0.66	0.66	0.65
	P1_30%	9.0	10.8	11.8	0.53	0.54	0.52
C1	ref P2_0%	13.0	16.0	18.5			
	P2_10%	10.3	11.7	13.0	0.79	0.73	0.70
	P2_20%	6.5	8.0	8.67	0.50	0.50	0.46
C2	ref P1_0%	33.3	36.1	39.6			
	P1_2%	29.5	33.1	36.3	0.89	0.92	0.92
	P1_4%	28.9	30.5	33.4	0.87	0.85	0.84
	P1_6%	26.5	28.9	31.5	0.79	0.80	0.80
	P1_30%	15.1	17.9	19.6	0.45	0.50	0.50
C2	ref P2_0%	34.0	36.0	39.4			
	P3_10%	24.5	28.2	31.7	0.72	0.78	0.81
	P3_20%	20.9	23.6	26.3	0.61	0.66	0.67
	P3_30%	12.5	13.9	15.3	0.37	0.39	0.39

5. CONCLUSIONS

The integration of plastic waste into concrete represents a promising solution to environmental challenges posed by plastic pollution. Recent studies have highlighted that incorporating plastic waste into concrete can affect its mechanical properties, both negatively and positively, depending on the type and quantity of plastic used. Generally, plastic in concrete mix leads to a reduction in compressive strength and workability, especially at higher addition levels, but it gains in terms of lightness. Therefore, concretes with plastic are ideal for the realization of non-structural and lightweight elements. Moreover, plastic in concrete mix exhibits higher absorption capacity and improved acoustic insulation compared to regular concrete. From an economic point of view, incorporating plastic aggregates in concrete production offers a cost-effective solution, saving sand resources and reducing fuel consumption and carbon emissions.

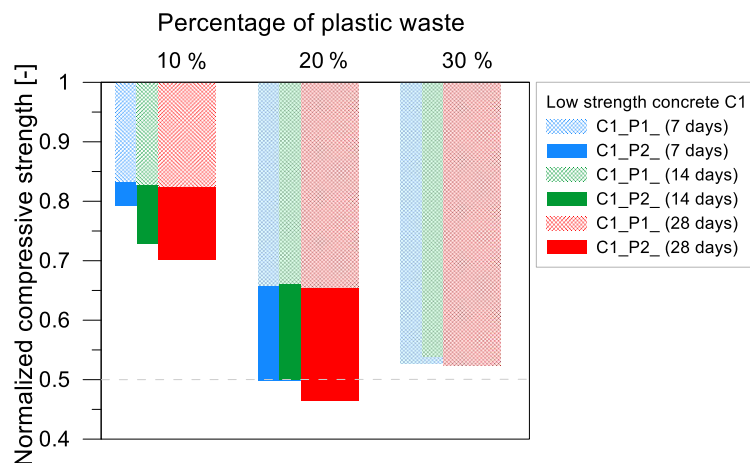


Figure 4. Normalized compressive strength vs. percentage of plastic aggregates: comparisons between concrete mixes C1 with light blue plastic flakes (P1) and plastic flakes (P2).

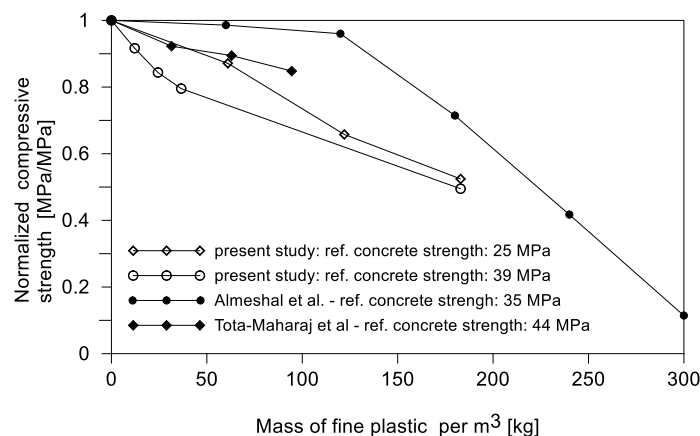


Figure 5. Comparison between the compressive strengths in the present study and some studies in the literature



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Experimental results provide that while adding plastic aggregates may slightly impact concrete strength up to 10%, significant decreases are observed beyond 20% addition. Moreover, it was observed that fine plastic aggregates are more suitable to reduce the loss of strength than coarser ones. In conclusion, although integrating waste plastic into concrete presents a sustainable approach to addressing plastic pollution and enhancing concrete performance, careful consideration of type of plastic, size and proportion is essential. Further studies are needed to explore optimal additive percentages and sustainable methods for assessing the size influence of waste plastics, thereby improving the feasibility of using recycled plastic in construction applications.

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REFERENCES

- [1] Li, X., Ling, T. C., & Mo, K. H. (2020). Functions and impacts of plastic/rubber wastes as eco-friendly aggregate in concrete–A review. *Construction and building materials*, 240, 117869.
- [2] Sweden, K. I. M. O. (2007). Small plastic particles in Coastal Swedish waters. N. *Research Report commissioned by KIMO Sweeden (Submitted to BDC)*.
- [3] Andrady, A. L. (2011). Microplastics in the marine environment. *Marine pollution bulletin*, 62(8), 1596-1605.
- [4] Wright, S. L., Thompson, R. C., & Galloway, T. S. (2013). The physical impacts of microplastics on marine organisms: a review. *Environmental pollution*, 178, 483-492.
- [5] Villarrubia-Gómez, P., Cornell, S. E., & Fabres, J. (2018). Marine plastic pollution as a planetary boundary threat–The drifting piece in the sustainability puzzle. *Marine policy*, 96, 213-220.
- [6] Prata, J. C., Silva, A. L. P., Da Costa, J. P., Mouneyrac, C., Walker, T. R., Duarte, A. C., & Rocha-Santos, T. (2019). Solutions and integrated strategies for the control and mitigation of plastic and microplastic pollution. *International journal of environmental research and public health*, 16(13), 2411.
- [7] Eriksson, O., & Finnveden, G. (2009). Plastic waste as a fuel-CO₂-neutral or not?. *Energy*

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& Environmental Science, 2(9), 907-914.

- [8] Jassim, A. K. (2017). Recycling of polyethylene waste to produce plastic cement. *Procedia manufacturing*, 8, 635-642.
- [9] Siddique, R., Khatib, J., & Kaur, I. (2008). Use of recycled plastic in concrete: A review. *Waste management*, 28(10), 1835-1852.
- [10] Tota-Maharaj, K., Adeleke, B. O., & Nounu, G. (2022). Effects of waste plastics as partial fine-aggregate replacement for reinforced low-carbon concrete pavements. *International Journal of Sustainable Engineering*, 15(1), 192-207.
- [11] Ferrotto, M. F., Asteris, P. G., Borg, R. P., & Cavaleri, L. (2022). Strategies for waste recycling: The mechanical performance of concrete based on limestone and plastic waste. *Sustainability*, 14(3), 1706.
- [12] Almohana, A. I., Abdulwahid, M. Y., Galobardes, I., Mushtaq, J., & Almojil, S. F. (2022). Producing sustainable concrete with plastic waste: A review. *Environmental Challenges*, 100626.
- [13] Federbeton Confindustria. Rapporto di Filiera 2019. (2020) Available online: <https://www.federbeton.it/>.
- [14] Alqahtani, F. K., Ghataora, G., Khan, M. I., & Dirar, S. (2017). Novel lightweight concrete containing manufactured plastic aggregate. *Construction and Building Materials*, 148, 386-397.
- [15] Thorneycroft, J., Orr, J., Savoikar, P., & Ball, R. J. (2018). Performance of structural concrete with recycled plastic waste as a partial replacement for sand. *Construction and Building Materials*, 161, 63-69.
- [16] Kaur, G., & Pavia, S. (2020). Physical properties and microstructure of plastic aggregate mortars made with acrylonitrile-butadiene-styrene (ABS), polycarbonate (PC), polyoxymethylene (POM) and ABS/PC blend waste. *Journal of Building Engineering*, 31, 101341.
- [17] Almeshal, I., Tayeh, B. A., Alyousef, R., Alabduljabbar, H., & Mohamed, A. M. (2020). Eco-friendly concrete containing recycled plastic as partial replacement for sand. *Journal of Materials Research and Technology*, 9(3), 4631-4643.
- [18] Sabău, M., & Vargas, J. R. (2018). Use of e-plastic waste in concrete as a partial replacement of coarse mineral aggregate. *Computers and Concrete*, 21(4), 377-384.
- [19] Poonyakan, A., Rachakornkij, M., Wecharatana, M., & Smittakorn, W. (2018). Potential use of plastic wastes for low thermal conductivity concrete. *Materials*, 11(10), 1938.

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- [20]UNI EN 12390-4 (2002). Testing hardened concrete – Part 4: Compressive strength – Specifications for testing machines. ASRO; 2002.
- [21]UNI EN 12390-2. (2009). Testing Hardened Concrete – Part 2: Making and curing specimens for strength tests.