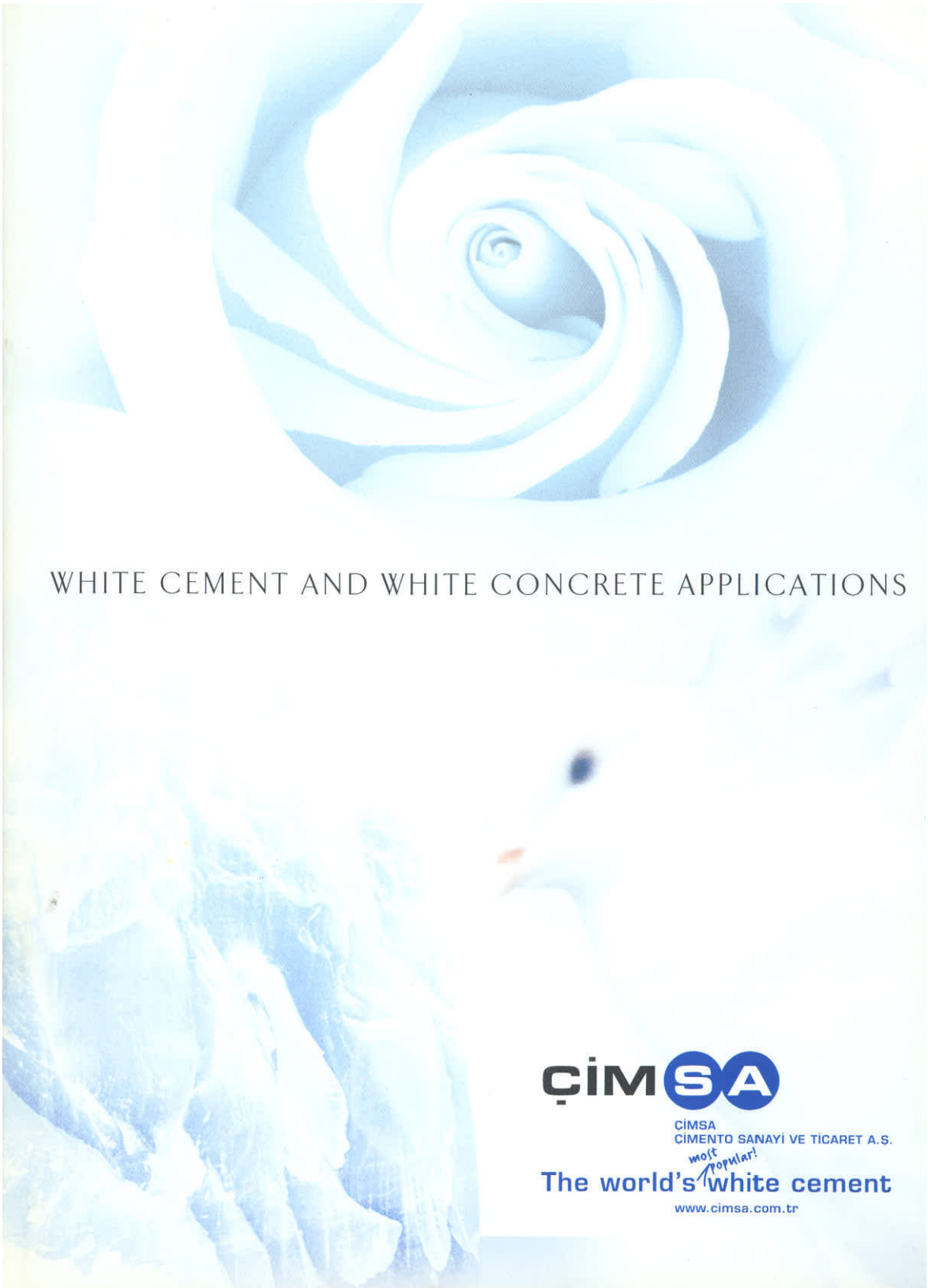
WHITE CEMENT AND WHITE CONCRETE APPLICATIONS
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CONTENTS

1. INTRODUCTION

Although white portland cement has been produced for more than a century, it is, rather, known by its aesthetics and decorative characteristics. The long-lasting low quality of white cements initially produced also contributed to this understanding. However, in consequence of both the use of high production technologies and the continuous development of quality-relevant knowledge and experience, currently, the quality of white cement has been enhanced significantly. White portland cement produced at Çimsa, has a nature of excellent white cement with superior properties from the standpoint of not only aesthetics and decorative characteristics, but also load carrying capacity.

This booklet includes theoretical and experimental information regarding white cement properties and its applications. Points that should be taken into consideration during production, placement and curing of white concrete are also stated.

2. PROPERTIES OF WHITE PORTLAND CEMENT

White cement is a special hydraulic binding material which sets and hardens when mixed with water and gains strength as a result of this hardening. Main properties that make white cement different from gray portland cement are as follows :

- Its raw material is too pure.
- Produced with high technology.
- Finely ground.
- High rate of strength gain.
- Both early and final strengths are high.
- Has aesthetics and decorative characteristics.
- Produced at high whiteness degree and with stable whiteness.
- Provides surface smoothness and beauty of appearance.
- When mixed with various pigments, bright and vivid colors are achieved.

Table I shows typical properties of super white portland cement, with comparisons to gray portland cement.

Table 1 - Comparative properties of Çimsa white portland cement with respect to gray portland cement

	TS EN 197-1 CEM I 52,5 N		TS EN 197-1 CEM I 42,5 R		TS EN 197-1 CEM II/B-M (V-L) 32,5 R	
PROPERTIES	ÇİMSA WPC	ST. VALUE	ÇİMSA PC	ST. VALUE	ÇİMSA PCC	ST. VALUE
SO_3 (%)	3.38	max. 4.00	3.15	max. 4.00	2.20	max. 3.50
Insoluble Residue (%)	0.12	max. 5.00	0.66	max. 5.00	-	-
Loss on Ignition (%)	2.61	max. 5.00	2.05	max. 5.00	3.5	-
Initial Setting Time (min.)	100	min. 45	150	min. 60	160	min. 60
Final Setting Time (min.)	125	-	185	-	195	-
Blaine Fineness (cm^2/gr)	4700	-	3450	-	3700	-
2 Day Compressive Strength (MPa)	38.0	min. 20.0	25.0	min. 20.0	17.0	min. 10.0
28 Day Compressive Strength (MPa)	59.0	min. 52.5	48.0	min. 42.5	37.0	min. 32.5

According to Table 1, from the point of performance criteria, Çimsa white portland cement is far above standard values and therefore is described as super white portland cement. Due to the high amount of C_3S and S_3A compounds and fine grinding, its rate of strength development and its strengths at early ages are high. Its hydraulic activity is very high. Due to this characteristic, it is commonly used in cases where early strength is the main issue, especially in pre-cast productions. Thanks to calcium silicate compounds (C_3S and C_2S) which determine binding properties, the ultimate strength of Çimsa white portland cement is also very high. These strength values are the highest among all existing cement types on the market, including gray portland cements. Because it takes place within a low-alkali cement class, it has a high durability against alkali-aggregate reactions. Also, volume expansion is low and whiteness is too high (min. 85% whiteness).

3. WHITE CEMENT & APPLICATION AREAS OF WHITE CONCRETE

White cement, which has such superior properties with respect to gray cement, is used in a very wide spectrum. The major application areas are as follows:

- Architectural and decorative concrete productions (trade and business centers, residence constructions, bridges, aesthetics and decorative structures, stadiums, etc.)

- Ready-mixed plaster and mortar productions (interior and exterior facades of structures, ceilings, roof insulations, airports and heliports, all kind of decorative works, swimming pools, water ducts, etc.)

- Adhesive and joint filling materials production (adhesives for marble, granite, ceramic and concrete floor tiles, structural grouting, all kind of impermeability works, etc.)

- Park and garden furniture designs (pavement stones, kerbs, flower pots, balcony patterns, concrete columns, outer panels, seating and benches, border stones, reinforced concrete grids, decorative works and works of art, walking tracks, park and garden arrangements, etc.)

- Design of works of art (small sculptures, monuments, scarfito applications, restoration, relieves, wall pictures, reproductions, etc.)

- Flooring productions (floor tiles with different colors and patterns, thin floor tiles, wash concrete, concrete paving blocks, crossed stone, sidewalk flooring plates)

- Pre-cast component productions (white prefabricated concrete elements, external facade coatings, decorative coating stones, prefabricated stairs and balconies, window sills, white briquettes, reinforced concrete channels, concrete blocks, etc.)

- Historical arts restoration works

3.1 - Pre-cast Elements

White cement is successfully used in pre-cast applications such as exterior facade panels, decorative coating stones etc. It is also frequently used in areas such as floor tiles, kerb-stones, prefabricated stairs, balconies, window sills and street furniture. Additionally, pre-cast applications such as white briquette and white press brick, concrete grids and pool edges are also included in the areas of use.

3.2 - Architectural Prefabricated Exterior Facade Panels

In the US and Europe, white cement is especially used in housing estate constructions and large scale projects such as convention centers and various concert halls. In such projects, architectural prefabricated exterior facade panels made of white concrete not only shorten the construction period but also contribute an aesthetic beauty to exterior facades. It also eliminates paint and plaster costs.

3.3 Ready-mixed Plasters and Mortars, Adhesives and Joint Filling Materials

Çimsa white cement is used as a main binding component in the production of white cement-based construction materials such as joint filling materials, ceramic tile adhesives, insulation and anchorage mortars, industrial floor mortars, ready-mixed plaster and repair mortars.

3.4 - Architectural and Decorative Concrete

In developed countries, white concrete is successfully used in reinforced concrete constructions such as convention centers, metro and train stations, communication towers, stadiums and sports areas, housing estate and residences, bridges, flyovers and retaining walls.

3.5 - Works of Art

White cement is also used in concrete sculptures, monuments, contemporary art works and in restoration of archaeological and art works.

4 - WHITE CEMENT AND ITS PROPERTIES

In order to study the effects of the properties of Çimsa white portland cement on concrete performance, a series of laboratory tests were conducted. In the experimental studies, white and gray portland cements whose properties are given in Table 1 were used.

4.1 - Aggregate Properties

In the experimental studies conducted, marble powder and mosaic were used as white aggregate, together with white cement, in the production of white concrete. Sieve analyses of four groups of white aggregates with different grain sizes are given in Table 2, whereas, specific gravities and water absorption capacities in saturated surface dry conditions are provided in Table 3.

Table 2 - Aggregate sieve analyses (passing through the sieve, in %)

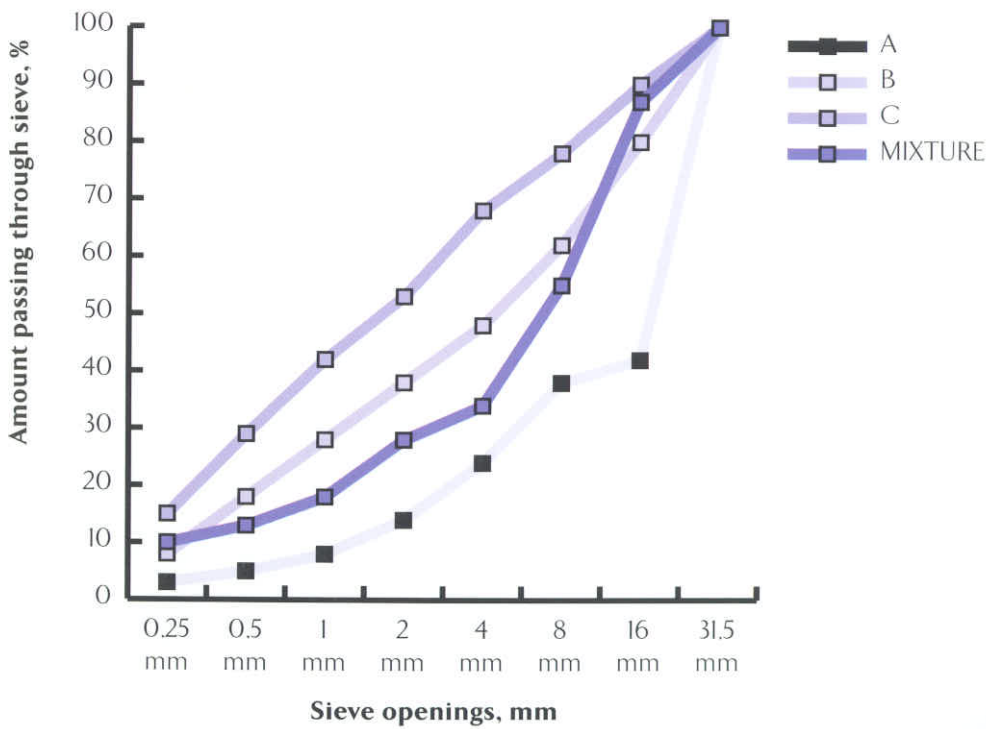
	SIEVE OPENING, mm							
Aggregates	31,5 mm	16 mm	8 mm	4 mm	2 mm	1 mm	0,5 mm	0,25 mm
Marble powder	100	100	100	100	100	92	70	49
Mosaic I	100	100	100	83	44	14	10	8
Mosaic II	100	100	59	3	1	1	1	1
Mosaic III	100	67	2	2	2	2	2	1

Table 3 - Physical properties of aggregates

	Marble powder	Mosaic I	Mosaic II	Mosaic III
Water absorption (%)	1.5	0.9	0.9	0.6
Specific gravity	2.67	2.65	2.83	2.70

Aggregate mixture with a maximum aggregate size of 31.5 mm is obtained upon combining four groups of broken marble aggregate at appropriate proportions. In the aggregate mixture prepared in accordance with the limits specified in TS 706 standard; marble powder, mosaic I, mosaic II and mosaic III are used at proportions of 15%, 25%, 25% and 35%, respectively. Sieve analysis of the aggregate mixture used in concrete and limits specified in standards are shown in the Figure I (between curves A and B: "very good"; between curves A and C: "can be used").

Figure I - Aggregate grading curve



4.2 - Comparison of White and Gray Portland Cement

In order to study the strength developments of concrete at early ages, three different types of concrete were produced by using different kinds of cements. In all concrete mixes, while the grading, slump and cement content were kept constant, the type of cement was changed to determine the effect of cement type on strength development. For the sake of comparison, all concretes were produced with a slump value of 6 cm. White aggregates which are suitable to the aggregate grading in Figure 1 were used in the concrete mixtures in which the cement dose was selected as 350 kg/m^3. Mix designs of concretes produced from various types of cements are given in Table 4.

Table 4 - Concrete mix proportions for a slump value of 6 cm (SSD basis)

MATERIALS	CEM I 52.5 N (White portland cement)	CEM I 42.5 R (Portland cement)	CEM II/B-M(V-L) 32.5 R (Portland composite cement)
Cement, kg/m^3	350	350	350
Water, kg/m^3	180	179	175
Marble powder, kg/m^3	285	285	285
Crushed marble I, kg/m^3	475	475	475
Crushed marble II, kg/m^3	475	475	475
Crushed marble III, kg/m^3	665	665	665
Water-reducer, %*	1.5	1.5	1.5
Water/Cement	0.51	0.51	0.50

* by mass of cement

In order to examine the strength developments of concrete produced by the use of different types of cements, compressive strength tests were conducted at the ages of 6 hours, 8 hours, 10 hours, 12 hours, 16 hours, 20 hours, 24 hours, 3 days, 7 days and 28 days. These values are given in Figure 2.

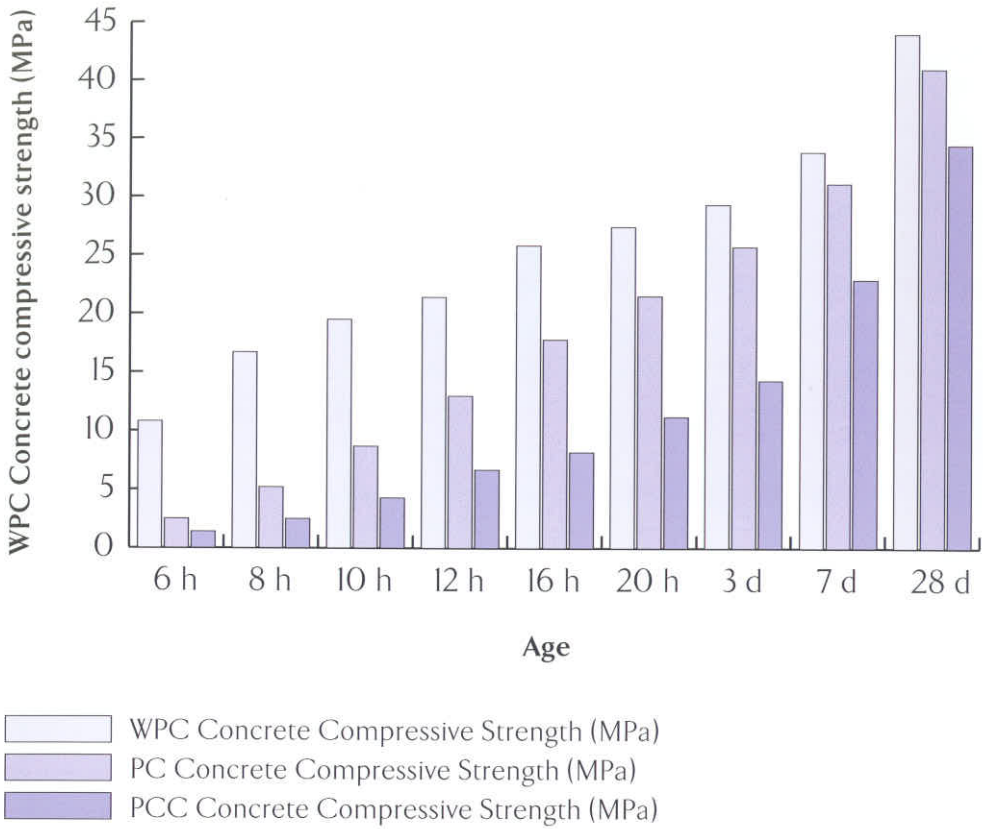


Figure 2 - Early compressive strengths of concrete produced by different cements

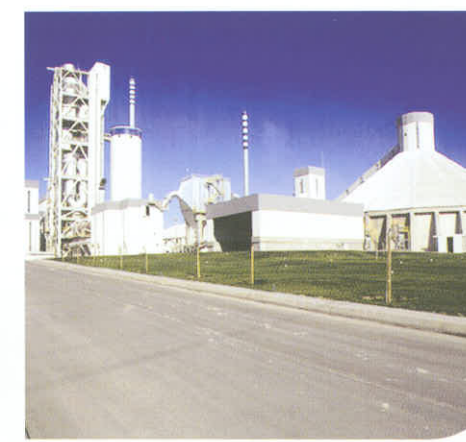
As seen from the Figure 2, both the early and ultimate compressive strength values of concretes produced by white portland cement are higher than those of concrete produced by gray portland cement. Concrete produced by WPC reaches the 28 day strength values of ready-mixed concrete class of C14 within 8 hours. WPC concrete gains almost 60% of its 28 day strength at 16 hours, whereas, PC and PCC concrete at the end of 24 hours and 3 days, respectively. Thanks to this property, concrete made of white cement allow early mould removal under normal curing conditions, without application of steam curing.

It is also seen that the ultimate strengths of concrete produced by white cement are higher than those of gray cement concrete. While 28 day strength value of WPC concrete is 43.9 MPa, those of PC and PCC concretes are 40.9 and 34.4 MPa, respectively.

Differences in strengths and in rates of strength development of mixes arise from physical and chemical properties of cements such as fineness and chemical composition.

As seen in Table I, the highest fineness value pertains to WPC. This high fineness resulted in that the concrete mixes with WPC have the highest strength values and the fastest strength development since the fineness of the cement influences the rate of strength development of concrete especially at early ages. This can be explained as follows: in the two cement samples having the same weights, the number of the cement particles are greater in the finer cement sample. In other words, the finer the cement, the higher is the number of the cement particles. Accordingly, in finer cement, the surface area that will come in contact with water is higher. Therefore, chemical reactions between cement and water (and thus the formation of hydration products) get faster and better, and strength development is accelerated (here, it is worth to note that hydration reactions start from the surface of the cement particles).

Chemical composition is another reason for the mixes produced with WPC to have the highest strength values and rate of strength development. It is well known that the main compounds of a cement sample (C_3S, C_2S, C_3A and C_4AF) have different properties. The hydration of C_3A is very fast; however, it affects the strength very little at a few hours and I day. C_3S is the main compound that is responsible from the early strength and its reaction speed is moderate. The reaction speed of C_2S is slower than that of C_3S at early ages. Therefore, the contribution of C_2S to strength is less at early ages but higher at later ages than that of C_3S. The long-term strength is obtained by the hydration of both C_3S and C_2S. As can be inferred from the foregoing explanations, the mixes with WPC have highest strength developments since the percentage amount of $C_3S + C_3A$ are the highest in WPC.



4.3 - White Concrete Design

A series of concrete tests were conducted in order to determine performance characteristics of white concrete at different white cement doses. White mosaic aggregates suitable to the grading curve in Figure I were used in concrete mixes where the dose of Çimsa white portland cement is between 250 kg/m^3 and 550 kg/m^3. All mixes were prepared with a slump value of 12 cm and by the use of superplasticizer at proportion of 1.5% by mass of cement. 3, 7 and 28 day compressive strength values of white concretes with different white cement doses are given in Figure 3.

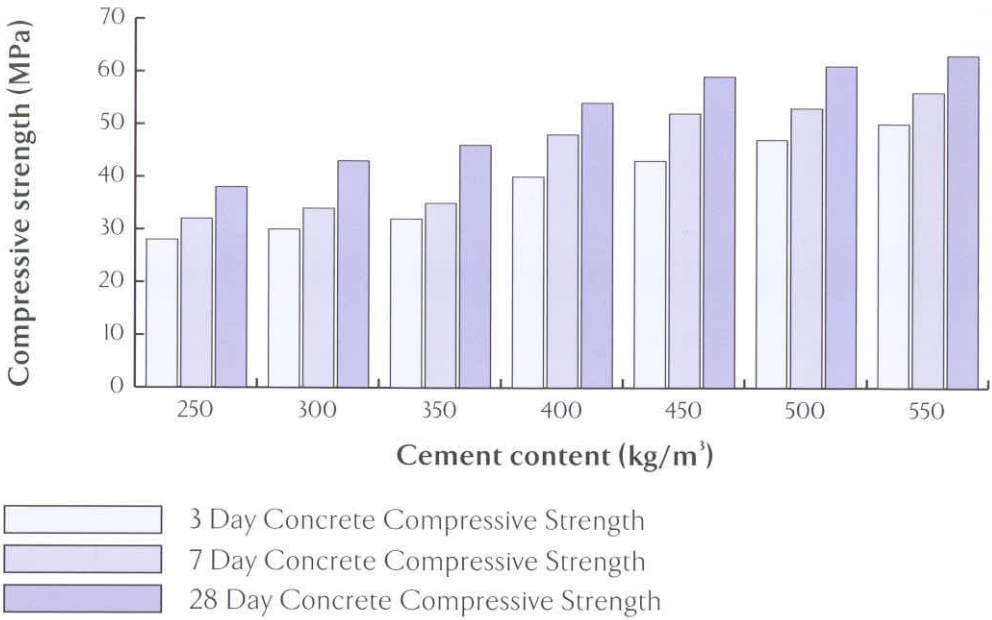


Figure 3 - Compression strengths of white concretes at different doses

As can be seen from the Figure 3, in use of 250-550 dose white cement, production of white concrete of all classes in the range of C_30 and C_50 stated in ready-mixed concrete standards is possible. As the cement dose increases in mixtures, 3, 7 and 28 day compressive strengths also increase.

4.4 - Issues to be Considered in White Concrete Production

• Because the surface in fair-faced concrete applications is expected to be pore-free and smooth, preparation and placement of concrete should be accurate. Time dependent slump loss should be controlled; if possible, concrete should be placed through a belt mixer or by the use of crane and bucket instead of a pump.

• Vibration of fresh concrete should be faultless.

• Curing of white concrete should be surveyed closely and, if possible, concrete should be wrapped with wet sacks or cloths.

• In white concrete mixtures, concrete and mortar additives used should be transparent in color.

• In concrete mixtures, white aggregates conforming to the grading and properties given in TS (Turkish Standards) 706 should be used. Essentially, cement and fine aggregate used are the factors that determine the color of white concrete. In WPC concretes prepared by attaching special importance on whiteness of aggregates (especially finer aggregates), desired whiteness values can be achieved.

• All materials added into concrete should be kept clean.

• Reinforcements used in reinforced concrete should be stain and dirt-free. When possible, galvanized reinforcement should be used.

• Moulds used should be made of low water absorbing material such as plywood. Moulds should be clean and cement paste should not leak out during vibration.

5 - ASSESSMENT

In concretes produced by white portland cement, both early and ultimate compressive strengths are significantly higher. When compared to gray cements on the market, due to its high rate of strength development, Çimsa white portland cement reaches extremely higher compressive strength values even at early hours without application of steam curing. This property allows increase in the production speed in concrete productions and, especially in prefabricated applications, reduces costs by eliminating steam curing applications and also removes the negative effect of steam curing on ultimate strengths of concretes. For these reasons, white cement is the cement type which is preferred in prefabricated applications.

High values of both early and ultimate strengths allow white concrete made of white cement to be also easily used in reinforced concrete. White concrete, which was first used as a fair-faced reinforced concrete in Turkey in the construction of the "White Cement Application Center" established on a closed area of approximately 1000 m^2 on the Çimsa Mersin Facilities, has various examples in the United States and Europe.

White cement and white cement-based white concrete applications are not only limited to fair-faced concrete and prefabricated applications. White cement and white concrete are used in production of various construction materials used in residences. Applications of ready-mixed plaster, joint filling and repair mortars, floor tiles, floor and wall coating plates and prefabricated stairs are some examples. In addition, white cement is a construction material commonly used in restoration of historical structures and in the design of city furnitures that are inevitable elements of urban culture.

Because of its characteristics which harmonize arts with architecture, engineering and technology, it has a wide range of applications in modern settlement areas. It is possible through white cement to transform concrete into a work of art.

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