Dokuz Eylül Üniversitesi İnşaat Mühendisliği Bölümü

YAPI MALZEMESİNDE ÖZEL KONULAR -4-

Prof. Dr. Halit YAZICI

Yüksek Performanslı betonlar

http://halityazici-deu.com

Beton dayanımı

ÖRNEK
- Boyutu
- Narinliği
- Nem durumu

BİLEŞENLERİN DAYANIMI

YÜKLEME ŞARTLARI
- Gerilme türü
- Uygulama hızı

MATRİS POROZİTESİ
- Su/Çimento Oranı
- Mineral Katkı
- Çimento Miktarı
- Hidratasyon derecesi
- (kür süresi, sıcaklığı, nem)
- Hava İçeriği
- (Hapsolmuş, Sürüklenmiş

AGREGA POROZİTESİ

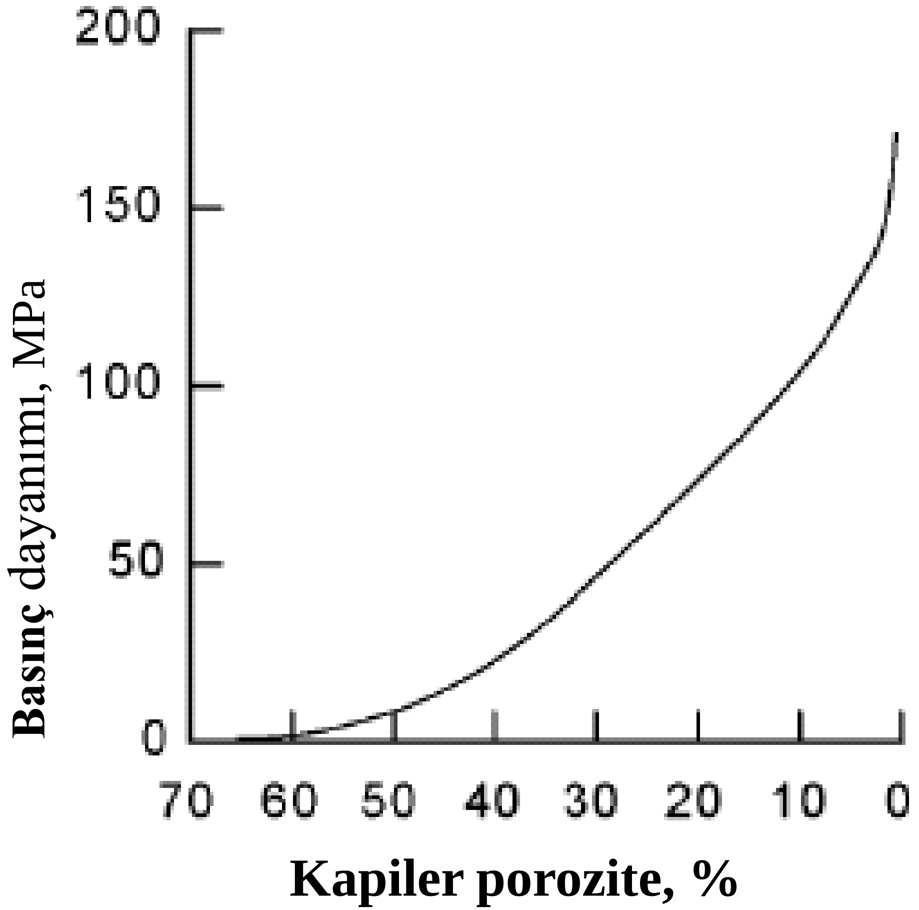
ARAYÜZEY POROZİTESİ
- Su/Çimento Oranı
- Mineral Katkı
- Terleme özellikleri (agrega maks. tane boyutu, tane dağılımı, geometri)
- Sıkışma derecesi, hidratasyon derecesi,(kür süresi, nem, sıcaklık)
- Agrega ile çimento hamuru arasındaki reaksiyon

Basınç dayanımı

- Çoğu katıda Temel ilişki
- $S = So * e^{(-kp)}$
- So: sıfır porozitedeki dayanım
- p: porozite
- k: sabit katsayı

Powers Modeli-çimento harcı

- $S=So(1-p)^3$
- Powers tarafından bulunan dayanım 234 MPa



200
150
100
50
0
70
60
50
40
30
20
10
0
Basınç dayanımı, MPa
Kapiler porozite, %

Su/Çimento Oranı

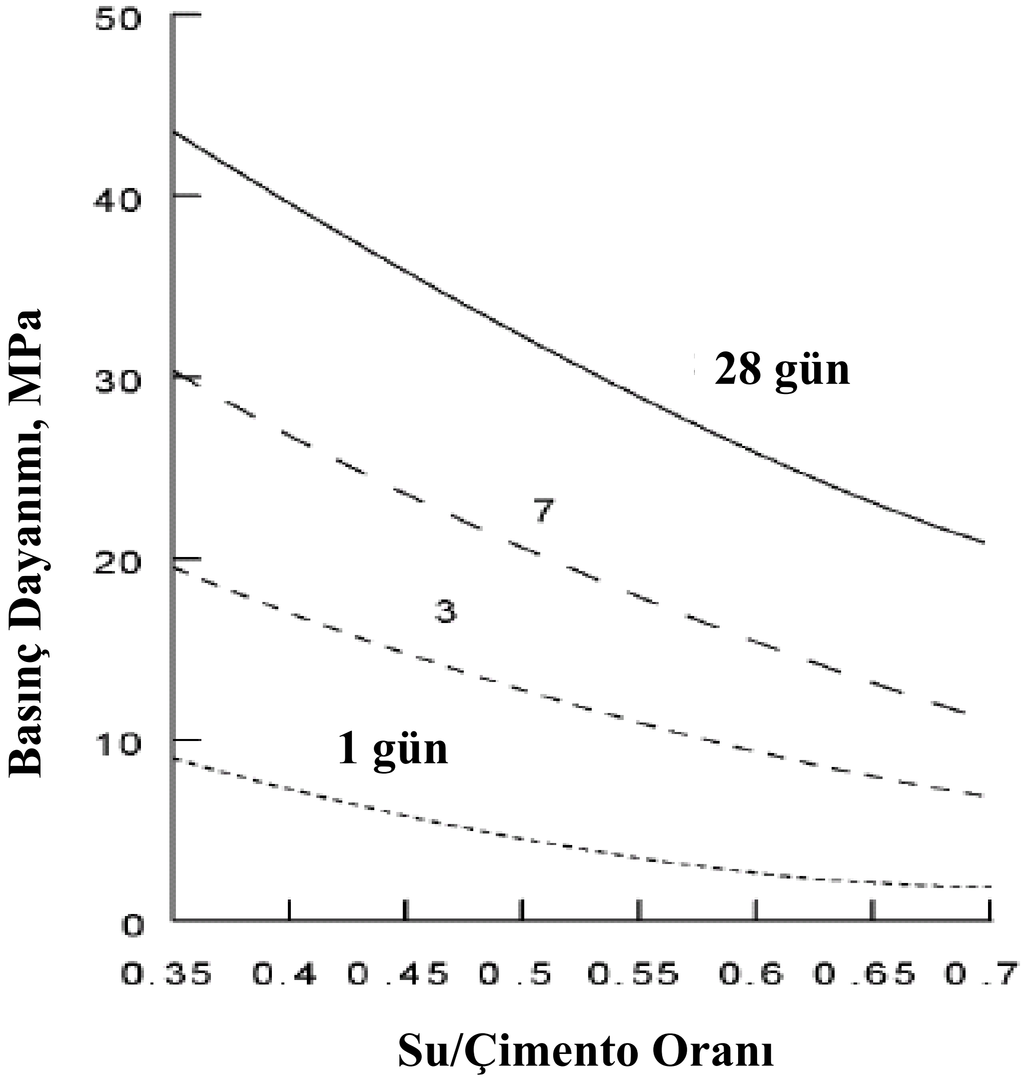
- Abram's Formülü

$$f_c = \frac{k_1}{k_2^{w/c}}$$

Burada w/c: beton karışımının su/çimento oranını, k1, k2: ampirik sabitleri temsil etmektedir.

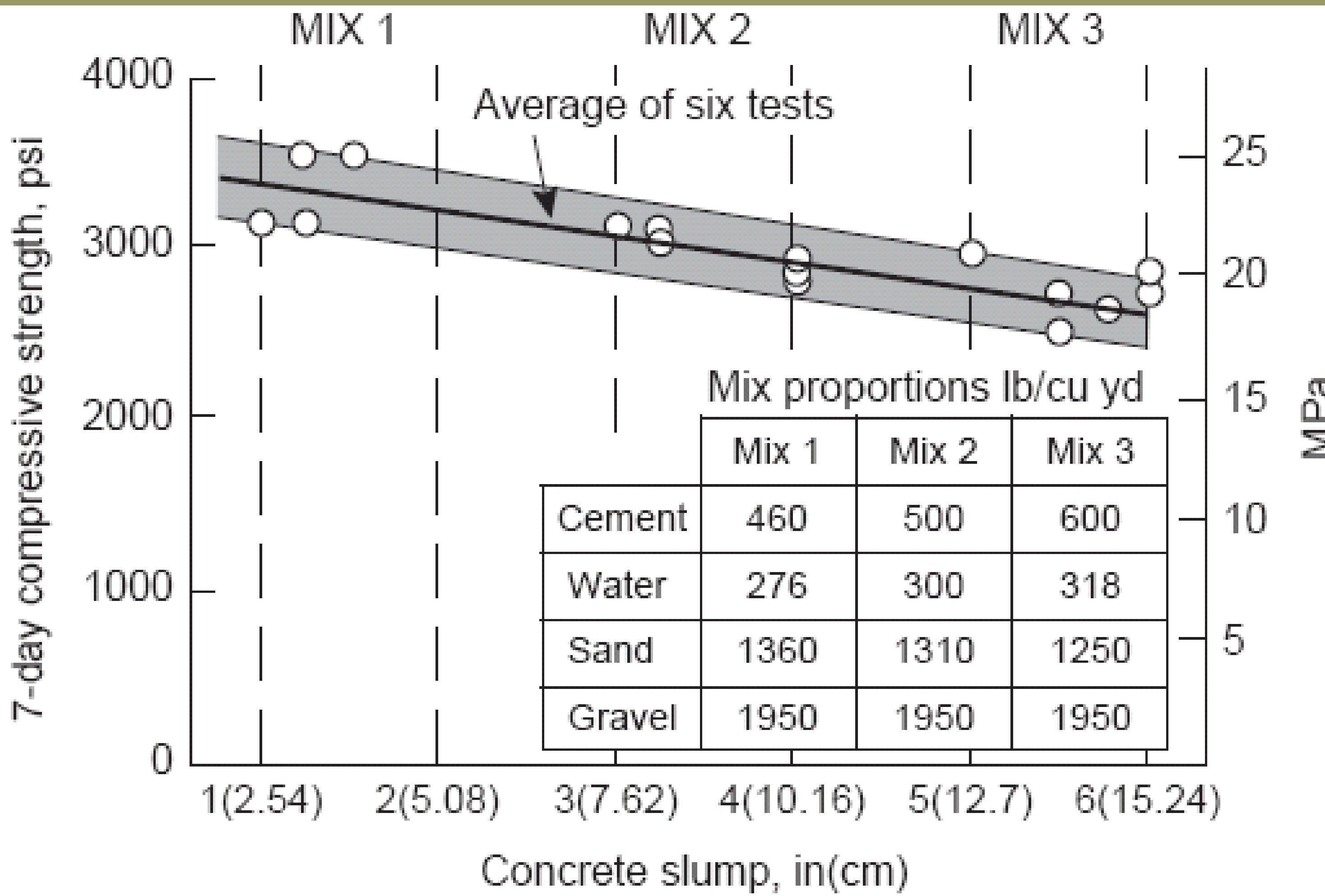
Agrega türünü, boyutunu, şeklini dikkate almayan bir formüldür.

Su/Çimento Oranı - Basınç Dayanımı ilişkisi



150x300 mm silindir

Normal Portland Çimentosu, Tip I



	Mix 1	Mix 2	Mix 3
Cement	460	500	600
Water	276	300	318
Sand	1360	1310	1250
Gravel	1950	1950	1950

Figure 3-6 Influence of the concrete slump on compressive strength and cost. (Data from student experiments, University of California at Berkeley.)

For a given water-cement ratio, concrete mixtures with higher slumps tend to bleed and therefore give lower strength. It is not cost-effective to produce concrete mixtures with slumps higher than needed.

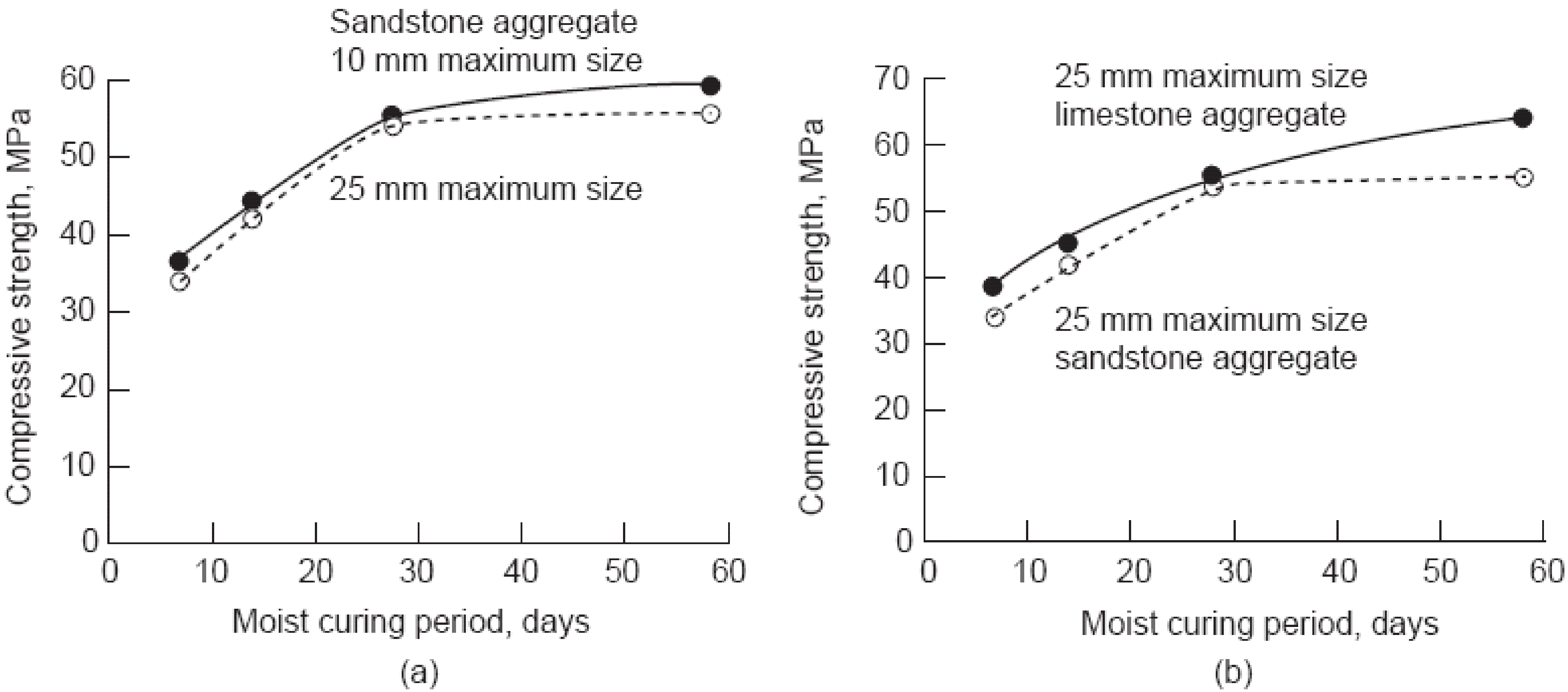
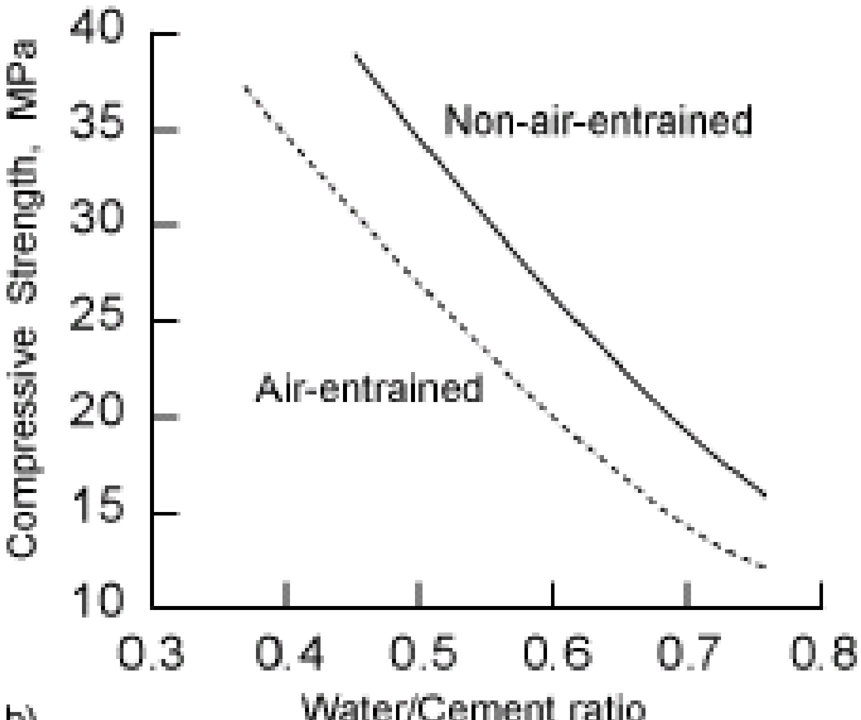


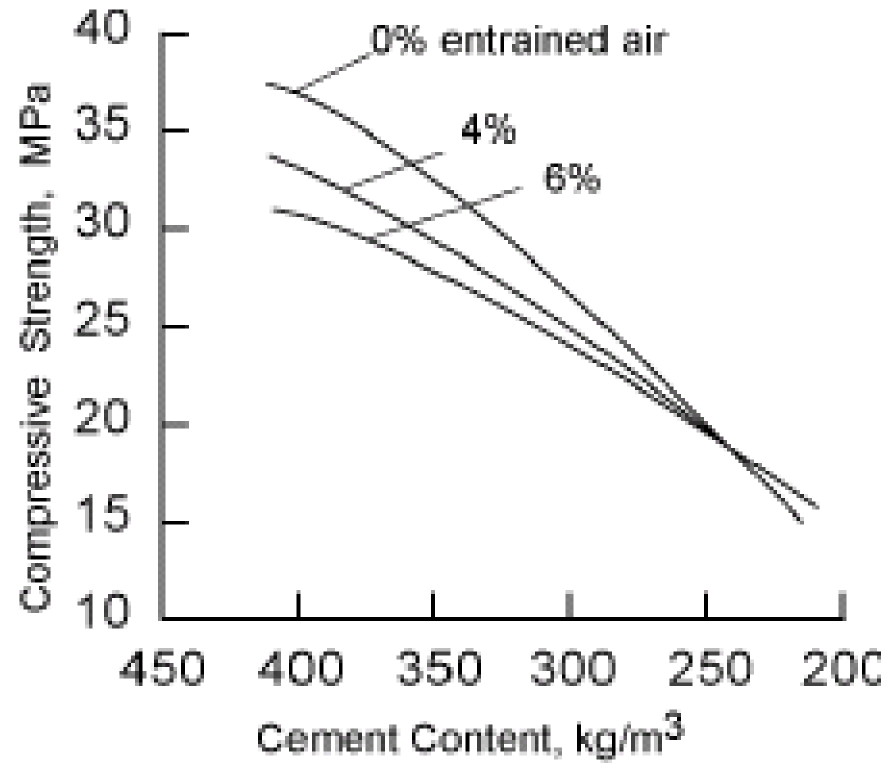
Figure 3-7 Influence of the aggregate size and mineralogy on compressive strength of concrete. (Data from students experiments, University of California at Berkeley.)

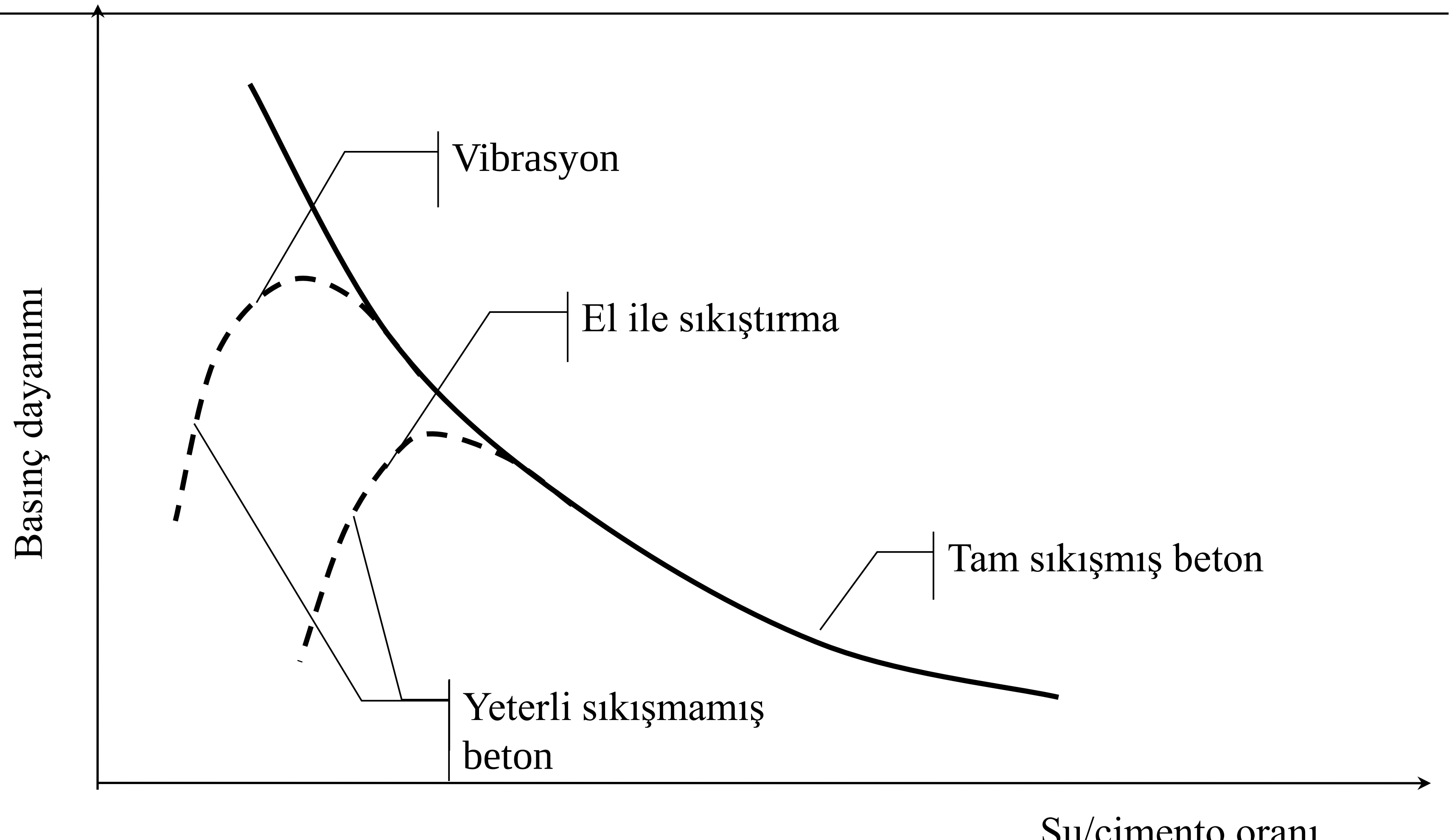
For a given water-cement ratio and cement content, the strength of concrete can be significantly affected by the choice of aggregate size and type.

Hava sürükleyici katkının etkisi



b)





Vibrasyon
El ile sıkıştırma
Tam sıkışmış beton
Yeterli sıkışmamış beton
Basınç dayanımı
Su/çimento oranı

Zamana bağlı dayanım kazanma

Zaman ile basınç dayanımının değerlendirilmesi yapı mühendisleri için önemli bir konudur.

ACI Committee 209, ASTM tip I normal Portland çimentosu ile yapılmış ve ıslak kür edilmiş beton için aşağıdaki ilişkiyi önermektedir:

$$f_{cm}(t) = f_{c28}\left(\frac{t}{4 + 0,85t}\right)$$

- 20 °C'de kür edilmiş beton örnekleri için CEB-FIB Models Code 1990 aşağıdaki ilişkiyi önermektedir:

$$f_{cm}(t) = \exp\left[s \left(1 - \left(\frac{28}{t/t_1} \right)^{1/2} \right) \right] f_{cm}$$

Burada;

fcm(t) = t gündeki ortalama basınç dayanımı

fcm= 28 gündeki ortalama basınç dayanımı

t1 = 1 gün

s = çimento tipine bağlı katsayı (erken dayanımı yüksek çimentolar için s=0.20, normal dayanımlı çimentolar için s=0.25, yavaş sertleşen çimentolar için s=0.38) olmaktadır.

Agreganın etkisi

- Köken
- Maksimum tane boyutu
- Tane dağılımı

Aggregate. With normal-strength concrete, *the type and amount of aggregate* plays an important role in the volume stability of concrete, but it has a limited influence on the strength. In high-strength concrete, the aggregate remains important for volume stability, but it also plays an important role on the strength and stiffness of concrete.

The low water-cement ratio used in high-strength concrete mixtures causes densification of both the matrix and the interfacial transition zone. Moreover, some aggregate types such as granite and quartzite may develop microcracks in the transition zone due to differential thermal shrinkage and, thus hinder the development of high mechanical strength.

Therefore, proper care must be taken in the selection of aggregates for high strength concrete. Based on the results of an experimental study, Aitcin and Mehta recommend that hard and strong aggregate types with high modulus of elasticity and a low coefficient of thermal expansion are better for producing very high-strength concrete mixtures

- Mehta ve Aitcin’e göre YPC’de
- Sert, güçlü ve elastisite modülü yüksek
- Düşük termal genleşmesi düşük olan kayaçlar agrega olarak kullanılmalı

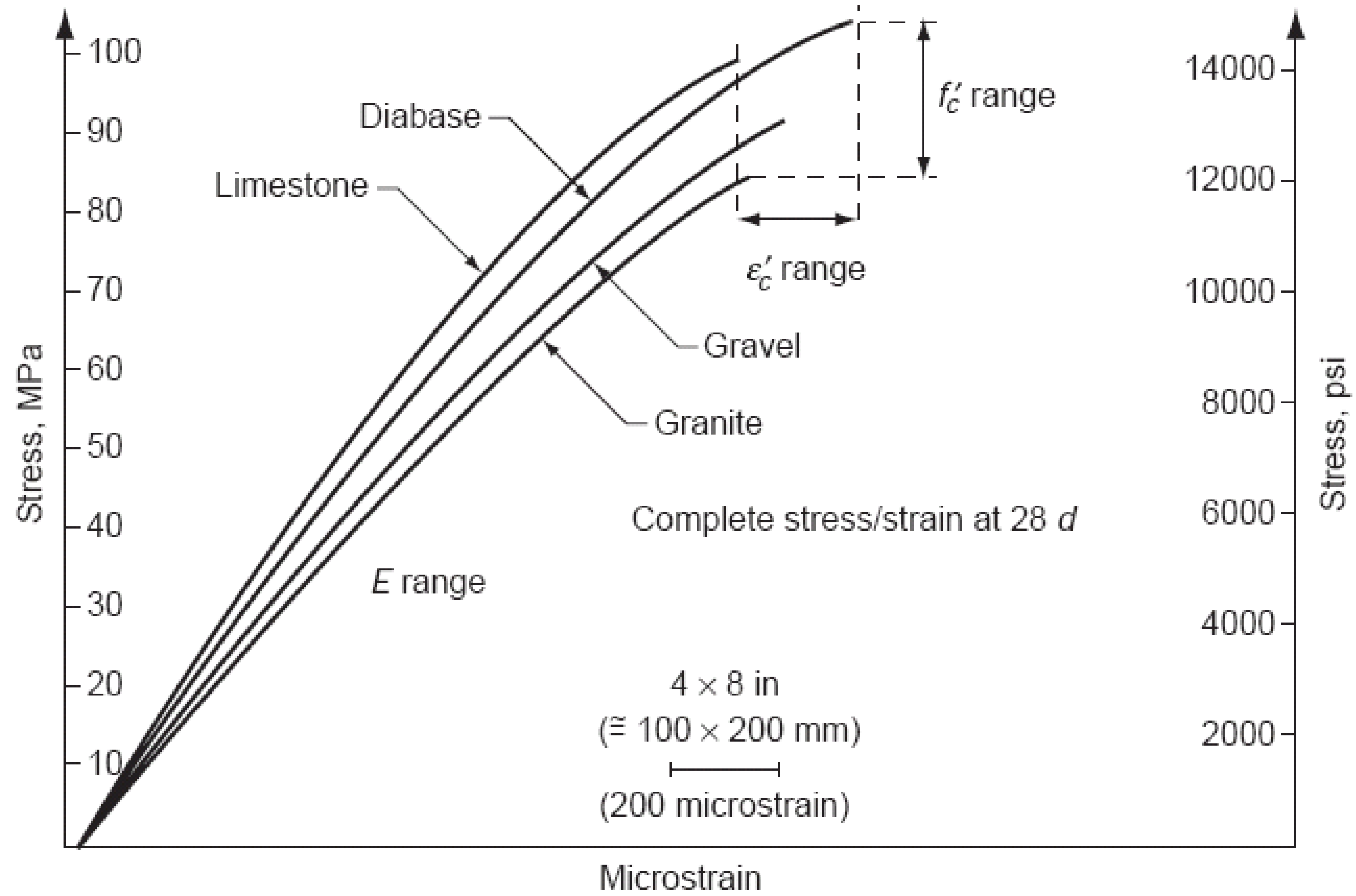


Figure 12-5 Stress-strain curves for high-strength concrete at 28 days. (Adapted from Aitcin, P.C., *High-Performance Concrete*, E & FN Spon, London, p. 591, 1998)

- As discussed, with a given water-cement ratio, the strength of a concrete mixture can be increased significantly by simply reducing the *maximum size of the coarse aggregate* because this has a beneficial effect on the strength of the interfacial transition zone. According to Aitcin the higher the targeted strength, the smaller should be the maximum size of coarse aggregate. Up to 70 MPa compressive strength concrete can be produced with a good-quality coarse aggregate of 20 to 25 mm maximum size.

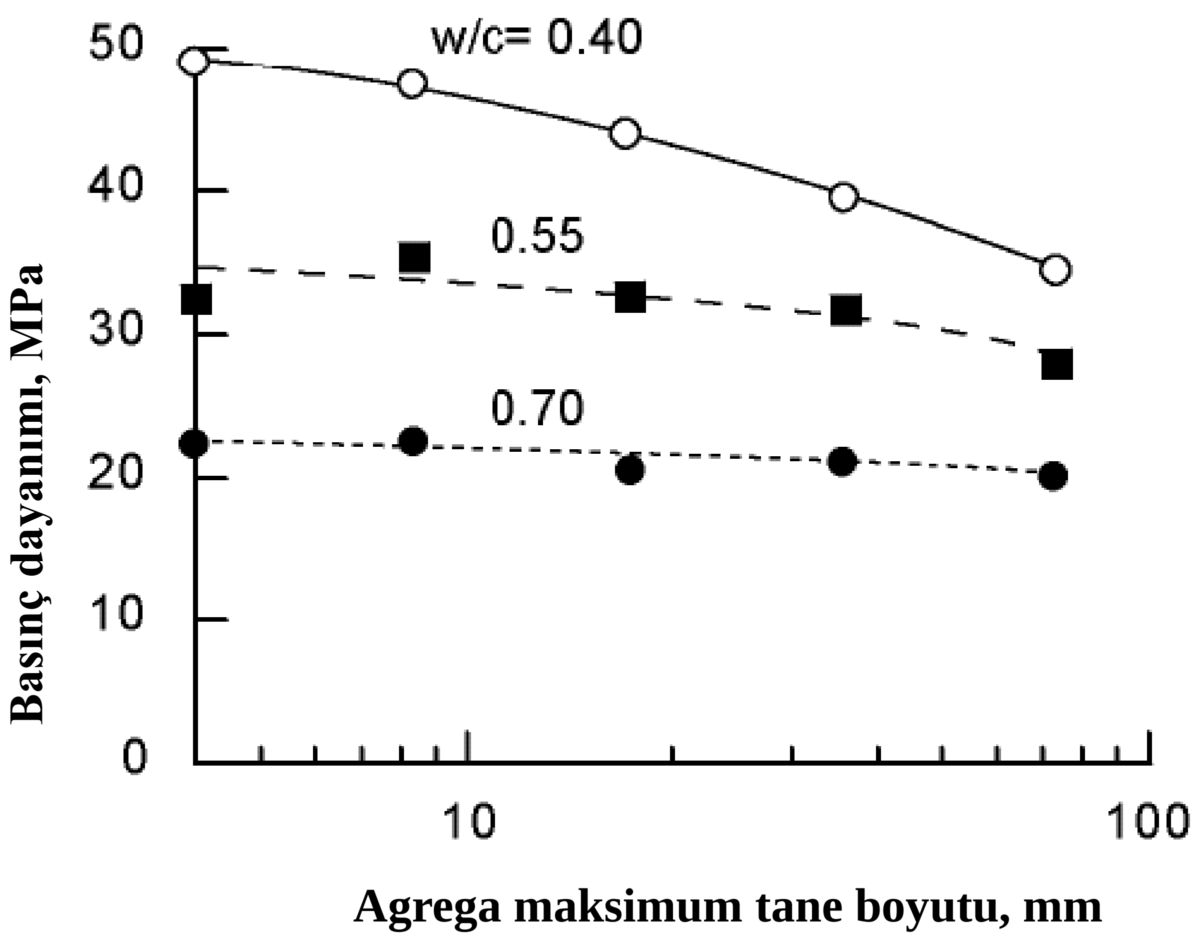
- Maksimum tane çapı küçültülerek mukavamet arttırılabilir
- 70 MPa için D maks=20-25 mm
- 100 MPa için Dmaks=14-20 mm
- 125 MPa için Dmaks=10-14 mm

- To produce 100 MPa compressive strength, aggregates with 14 to 20 mm maximum size should be used. Commercial concretes with compressive strengths of over 125 MPa have been produced with 10 to 14 mm maximum size coarse aggregate.

- In regard to fine aggregate, any material with the particle size distribution meeting the ASTM Standard Specification C 39 is adequate for high-strength concrete mixtures.
- Aitcin recommends using fine aggregates with higher fineness modulus (approx. 3.0) for the following reasons: (a) high-strength concrete mixtures already have large amounts of small particles of cement and pozzolan, therefore, the presence of very small particles in the fine aggregate is not needed to improve the workability, (b) the use of a coarser fine aggregate requires less water to obtain the same workability, and (c) during the mixing process, the coarser particles will generate higher shearing stresses that help to prevent the flocculation of cement particles.

- İncelik modülü yüksek olan kum kullanılabilir
- Karışımda zaten fazla miktarda toz var dolayısıyla kumun daha kaba seçilmesi su ihtiyacını azaltmak açısından avantaj
- Kaba kum ince tozların topaklaşmasını azaltabilir

Maksimum Tane Boyutu



Sabit çimento dozajı ve işlenebilirlikte

Agrega tane çapı arttıkça betonun su ihtiyacı azalır, dayanım artar

Agrega tane boyutunun artması daha zayıf arayüzey anlamına gelir

Net etki?

- **Cement.**
- Ordinary portland cement of any type (e.g., meeting ASTM C 150 Standard Specification) can be used to obtain concrete mixtures with compressive strengths up to 50 MPa. To obtain a higher strength while maintaining good workability, it is necessary to use chemical and mineral admixtures in combination with cement. In such cases, cement-admixture compatibility becomes an important issue. Experience has shown that, with naphthalene or melamine sulfonate type superplasticizers, low-C3A and low-alkali portland cements generally produce concrete mixtures which do not show high slump loss with time. This situation has changed because it is reported that polyacrylate copolymers, a new generation of superplasticizers, do not cause excessive slump loss with most types of portland, or blended portland cements.

- Çimento katkı uyumu önemli
- C3A ve alkalisi düşük çimentoların zamanla işlenebilirlik kayıpları daha az

- **Admixtures.** Depending on the desired properties, a high-strength concrete may contain one or more types of chemical admixtures, such as plasticizing, setcontrolling, and air-entraining. Also, for reasons discussed in the next paragraph, it is common to use mineral admixtures such as fly ash, slag, and silica fume.

- Poorly crystalline calcium silicate hydrate (C-S-H) is the major phase present in hydrated portland cement pastes; crystalline phases such as calcium hydroxide and capillary pores may be considered as microstructural inhomogeneities in the system. If microstructural inhomogeneities in the hydrated portland cement paste are strength limiting, the obvious solution is to modify the microstructure so that the components causing the inhomogeneities are either completely eliminated or reduced. In the case of cement products, an inexpensive and effective way to achieve this objective is through the *incorporation of a pozzolanic material*.

- In addition to cost reduction and a more homogeneous end product when a part of the portland cement in concrete is replaced by a pozzolan, another major benefit accrues in the form of lower temperature rise due to less heat of hydration. Because of the high cement content, the users of high-strength concrete mixtures frequently experience thermal cracking in large structural elements. Thus, in certain cases, reducing the risk of thermal cracking is by itself enough of a justification for partial cement replacement with a pozzolan.

Mixture proportioning

aggregate size mean that the cementitious materials content of the concrete mixture would be high, typically above 400 kg/m3. Cementitious contents of 600 kg/m3 and even higher have been investigated but are undesirable for reasons of high cost and excessive thermal and drying shrinkage.

- Furthermore, with increasing proportion of cement in concrete, a strength plateau is reached, that is, there is hardly much strength gain above a certain cement content. As explained above, this is probably due to the inherent inhomogeneity of the hydrated portland cement paste that contains randomly distributed areas of crystalline calcium hydroxide within the principal phase (i.e., poorly crystalline calcium silicate hydrate). These areas present weak regions that are vulnerable to microcracking under tensile stress.

- Puzolan kullanımının birçok avantajı var
- Yüksek olan çimento miktarını azaltabilmek
- Hidratasyon ısısının azalması
- Su ihtiyacının azalması
- Arayüzeyin takviyesi gibi

Mehta and Aitcin

- According to this method, high-strength concrete mixtures are classified into five strength grades, with 28-day compressive strengths 65, 75, 90, 105, and 120 MPa. To keep the drying shrinkage and creep low, the cement paste aggregate volume ratio is fixed at 35:65.

- Bu metoda göre
- 65, 75, 90, 105 ve 125 MPa olmak üzere beş mukavemet seviyesi belirlenmiştir
- Çimento hamuru/agrega oranı 35:65 olarak seçilmiştir (düşük büzülme ve sünme için)

- The strength enhancement is achieved by reducing the water content with the help of a superplasticizing admixture, and by partial substitution of cement with mineral admixtures. Also, as a first approximation, the fine-coarse aggregate volume ratio is kept at 2:3.

- Mukavemet artımı süperakışkanlaştırıcı ile su miktarını azaltarak
- Ve mineral katkı ile homojenliği bozan öğelerin azaltılması (Ca(OH)2)
- Ara yüzeyin takviyesi ile olmaktadır
- İlk denemede ince agrega/kaba agrega oranı 2/3 olarak alınmaktadır

- Depending on the desired rate of strength development and the local availability of fly ash (FA), ground granulated blast furnace slag (BFS), and condensed silica fume (CSF), this procedure offers the concrete producer three options, that is, use only portland cement (PC), use portland cement in combination with fly ash or slag, or use portland cement in combination with silica fume and fly ash or slag.

Calculated Mixture Proportions for the First Trial Batch According to the Mehta and Aitcin's Procedure, kg/m3

Strength grade	Avg. strength (MPa)	Option	Cementitious materials: PC	FA or BFS	CSF	Total* water	Coarse agg.	Fine agg.	Total batch	W/C
A	65	1	534	–	–	160	1050	690	2434	0.30
		2	400	106	–	160	1050	690	2406	0.32
		3	400	64	36	160	1050	690	2400	0.32
B	75	1	565	–	–	150	1070	670	2455	0.27
		2	423	113	–	150	1070	670	2426	0.28
		3	423	68	38	150	1070	670	2419	0.28
C	90	1	597	–	–	140	1090	650	2477	0.23
		2	447	119	–	140	1090	650	2446	0.25
		3	447	71	40	140	1090	650	2438	0.25
D	105	–	–	–	–	–	–	–	–	–
		2	471	125	–	130	1110	630	2466	0.22
		3	471	75	42	130	1110	630	2458	0.22
E	120	–	–	–	–	–	–	–	–	–
		2	495	131	–	120	1120	620	2486	0.19
		3	495	79	44	120	1120	620	2478	0.19

*The mix proportions are for non-air-entrained concrete, although 2 percent entrapped air is assumed. Total water includes the water in the superplasticizing admixture, the dosage of which may range from 3 to 10 l/m^3, depending on the consistency and strength requirements, cementitious content, and superplasticizer type.

Mix Proportions of High-Strength Superplasticized Concrete Mixtures Commercially Produced in Chicago Area

kg/m^3	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
Portland cement, Type I	564	475	487	564	475
Silica fume	–	24	47	89	74
Fly ash	–	59	–	–	104
Coarse aggregate, (10 mm max. size)	1068	1068	1068	1068	1068
Fine aggregate (Crushed dolomite)	647	659	676	593	593
Total water	158	160	155	144	152
Water-cementitious ratio	0.28	0.29	0.29	0.22	0.23

SOURCE: Adapted from Burg, R.G., and B.W. Ost, Research and Development, Bull. RD104, *Portland Cement Association*, p. 62, 1994.

Properties of Commercially Available High-Strength Concrete

kg/m^3	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
Compressive strength of moist-cured cylinders, MPa (ASTM C39)					
Age, days					
3	58.3	57.6	55.3	74.8	55.6
7	65.9	71.9	72.9	95.6	79.5
28	78.6	88.5	91.9	118.9	107.0
56	81.4	97.3	94.2	121.2	112.0
91	86.5	100.4	96.0	131.8	119.3
272	98.5	107.6	98.1	134.7	129.8
Tensile strength of moist-cured cylinders, MPa (ASTM C496)					
91 days	6.4	5.9	5.0	7.2	6.6
Modulus of rupture of moist-cured prisms, MPa (ASTM C78)					
91 days	9.4	10.1	9.9	13.7	9.6
Modulus of elasticity of moist-cured cylinders, GPa (ASTM C78)					
91 days	45.8	47.0	46.4	51.4	48.5
Drying shrinkage of prisms, millionth (ASTM C157)					
90 days	573	447	383	320	340
400 days	703	593	530	473	483
Rapid chloride permeability of concrete, Coulombs AASHTO, T277 (ASTM C157)					
287 days	2570	650	580	108	n.a.

Microstructure

- The description of the interfacial transition zone, This porous zone, where cracks often originate, prevents efficient load transfer between the coarse aggregate and the cement mortar. From the materials and mix designs used for making high-strength concrete mixtures, it is to be expected that the microstructure of the product is relatively free from inhomogeneities. With aggregate particles that are hard and strong, and with a strong interfacial transition zone due to the pore refinement and grain refinement, the microstructure of high-strength concrete permits efficient load transfer between the cement mortar and the coarse aggregate. Thus, the high elastic modulus and other mechanical properties of the material are directly attributable to the microstructure.

- Yüksek performans içyapıdaki gelişme ile sağlanmaktadır
- Yüksek oranda ince madde terleme-kusma problemini ortadan kaldırmaktadır
- Gözeneklerin azalması ve incelmesi, ince reaktif maddeler arayüzeyi geliştirir. Yüksek mukavemetli agregalar ile matris arasında iyi yük transferi gerçekleşir

- **Consistency.** By using a heavy dosage of the superplastizer, it is possible to obtain slump values on the order of 200 to 250 mm with concrete mixtures containing a very low water content, and a high content of cement and mineral admixtures. The presence of large amounts of fines helps to reduce the tendency for bleeding and segregation in these high-consistency mixtures. The construction of heavily reinforced, cast-in-place, shear walls, columns, floors, and other highstrength structural members in high-rise buildings would have been difficult without the availability of concrete mixtures possessing high workability.

- Yeni nesil akışkanlştırıcılar ile çok düşük su/bağlayıcı oranlarında bile 200 mm çökme elde edilebiliyor
- Yoğun donatılı dar kesitlere yerleşebilmeli

- **Thermal shrinkage.** In addition to autogenous shrinkage, massive structural members made of high-strength concrete mixtures are generally vulnerable to early-age cracking from thermal shrinkage that can be very high when freshly cast concrete is exposed to a cool ambient temperature within a few days after casting. Due to the high cement content, the adiabatic temperature rise is considerable in the case of high-strength concrete mixtures. For example, Mix 1-5 (Table), Burg and Ost13 reported 50 to 58°C temperature rise in thermocouples installed at the center of 1220 mm cube specimens within a period of 30 to 50 h after casting.

- Yüksek çimento dozajı, düşük S/B oranı yüksek hidratasyon ısısına yol açar
- Yukarıdaki Mix1-5 karışımlarında
- Dökümden 30-50 saat sonra 122 cm küpün merkezinde 50-58 C sıcaklık artışı ölçülmüştür.

- **Drying shrinkage and creep.** The data in above Table show that, in spite of low water content and high-quality aggregate, the long-term (400 days) drying shrinkage values of typical high-strength concrete mixtures (Mix 1, 2, and 3) ranged between 500 and 700 microstrain. Such high-drying shrinkage values are attributed to the high cementitious content of high-strength concrete mixtures. A slight reduction in drying shrinkage was observed when the water/cementitious material(w/cm) was reduced from 0.29 to 0.22 or 0.23 (Mix 4 and 5).

- Kuruma büzülmesi
- Yukarıdaki karışımlarda 500-700 mikrostrain kuruma büzülmesi oluşmuş
- Bu yüksek değerler bağlayıcının çok agreganın az olmasına bağlanabilir

- Burg and Ost13 also reported the specific creep data for the high strength concrete mixtures of Table 12-4, under sustained loading for 430 days. The applied stress was equal to 39 percent of the compressive strength of concrete. As expected, the specific creep was lowest for the concrete mixtures with highest strength. The specific creep was approximately 64 millionth/MPa for Mix 1, and 25 millionth/MPa for Mix 4. These values are 1/2 to 1/3 of the specific creep typically reported for ordinary concrete. Note that a combination of the high drying shrinkage and low creep is also responsible for the high cracking potential of cast-in-place, high-strength concrete mixtures.

- Specific creep (sünme/gerilme)
- Dayanımın %39'u kadar gerilmeye maruz örneklerde
- 25-60 microstrain/MPa
- Bu değer normal betonun ½-1/3'ü kadar
- Yüksek büzülme-düşük sünme çatlama riskini arttırır

- **Strength.** Several conclusions can be drawn from the data in Table 12-6, which is valuable because it represents typical behavior of modern high-strength concrete mixtures. First, with compressive strengths ranging from 90 to 130 MPa at 91 days, note that 50–75 MPa strength was attained at the early age of 3 days. Therefore, the benefit from the use of such high-strength mixtures is obvious for high speed construction and for precast and prestressed concrete products.

YPB de

- Dayanım kazanma hızı normal betondan çok daha hızlı
- 90 günlük mukavemetin %50-75'ini 3 günde alabilir
- Böylece inşaat hızı arttırılabilir

- Second, compared to the reference concrete (Mix 1), 40 to 50 percent enhancement in the 91-day compressive strengths was achieved with a combination of lower w/cm and partial substitution of cement by either silica fume (Mix 4), or by silica fume and fly ash (Mix 5). However, at the early age of 3 days, only Mix 4, with 14 percent silica fume and 0.22 w/cm, gave higher strength than the reference concrete mixture.

- From the 91-day tensile and flexural strength data, tensile-compressive strength ratio in high strength concrete was approximately 5.5 to 6 percent, whereas the flexural-compressive strength ratio was about 10 percent. Due to the relatively more brittle microstructure, these values are significantly lower than the typical values with conventional concrete.

YPB de

- Çekme dayanımı/basınç dayanımı oranı

%5.5-6

Eğilme dayanımı/basınç dayanımı oranı %10

Bu değerler HPC'nin kırılgan davranışı nedeniyle normal betondan düşük

- With high-strength concrete, due to a decrease in microcracking in the interfacial transition zone, the ascending branch of the stress-strain curve is steeper and more linear to a higher percentage of the peak strength than with normalstrength concrete. Iravani and MacGregor reported linearity of the stress-strain diagram at 65 to 70, 75 to 80, and above 85 percent of the peak load for concrete with compressive strengths of 65, 95, and 105 MPa.

YPB

- HPC'nin gerilme-birim şekil değiştirme eğrisinin çıkış eğimi daha büyüktür
- Daha yüksek gerilme/dayanım oranına kadar eğri doğrusaldır
- 65 MPa >>>> %65-70
- 95 MPa>>>>>> %75-80
- 105 MPa>>>   %80-85

HPC

- From their experimental study, the authors suggested the following *strength values for sustained loading:*
- 70 to 75 percent (of the short-time loading strength) for 65 MPa concrete,
- 75 to 80 percent for 95 MPa concrete without silica fume, and
- 85 to 90 percent for 105 MPa concrete with silica fume.

- These results indicate that the reduction in porosity, which is necessary for strength, helps to delay the formation and propagation of microcracks, thus increasing the allowable sustained load. Silica fume contributes to the densification and grain refinement of the cement paste and the interfacial transition zone, therefore, it is not surprising that its use increases the allowable sustained load.

- Porositenin azalması, ITZ’in gelişmesi, homojenliğin arttırılması, silis dumanı kullanılması gibi önlemler mukavemet artışı yanısıra mikro-çatlak oluşumu ve gelişimini geciktiriyor.

- **Elastic modulus.** The data in Table 12-6 show that, with 91-day-old highstrength concrete mixtures of approximately 0.29 w/cm, there was an upper limit of about 47 GPa modulus of elasticity in compression. Note that all five concrete mixtures contained a high quality coarse aggregate (crushed dolomite, 10 mm max. size). A slight increase in the modulus was obtained only when the w/cm was reduced to 0.22 and a significant amount of cement was replaced with silica fume and fly ash (Mix 4 and 5).

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