Lab 2: Making & Curing Concrete – ASTM C31, Slump Test – ASTM C143, Air Content Tests – ASTM C231, Rebound Hammer Test – ASTM C805, Ultrasonic Pulse Velocity Test – ASTM C597, Compressive Strength of Concrete – ASTM C39

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Objective

Following the mixing and curing of the concrete, the slump test, and air content test we should be able to:
• Create an appropriate concrete mix.
• Discuss the effect of water cement ratio on the slump amount.
• Define and discuss the importance of air content in freshly mixed concrete.

Following compressive strength of concrete test, the ultrasonic pulse velocity test, and the rebound hammer test we should be able to:
• Realize and discuss the difference between destructive and non-destructive tests for assessing the compressive strength of concrete.
• Define and discuss the effect of curing time on the concrete compressive strength.

ASTM C31 is widely used as the way to mix concrete on site. While ASTM C143 and ASTM C231 are used to see if there is the correct amount of water and air, respectively, for the condition laid out. ASTM C805 is commonly used on structures and structure components not concrete test cylinders, but if used on concrete cylinders it can give a relative sense of the hardness of the concrete. While ASTM C597 is commonly used to test for defects in the concrete structures. ASTM C39 is used concrete manufacturing and mixing plants to test a batch to qualifications.

Test Results

Table 1: Concrete Mix Components for Group 13

Concrete Componet	Quantity Assigned	Actual Quantity Used
Cement (lbs)	37.35	37.35
Course Aggregate (lbs)	69.51	69.51
Fine Aggregate (lbs)	62.24	62.24
Water Content (lbs)	15.6	18.429

Table 1 shows the quantity of each mix ingredient assigned and the actual quantity used in our mix. Since our concrete mix was not fully saturated with the water initially assigned extra water was added. The extra water added was measured by measuring the weight of the bucket with the extra water, then some was added slowly and until the mix was saturated, and finally the bucket was weighed and the difference was the amount of extra water added.

Table 2: Slump and Air Percentage Measurements for Group 13

Slump Test	Data
Slump Measure (inches)	2.75
Slump Type	Normal
Air %	4

Table 2 shows the slump test results and the air content results. The slump type for our group was normal with a slump of 2.75 inches which was within the limitations set at the start of the lab. Our air content was measured to be 4 percent.

Table 3: Compressive Strengths of Concrete Cylinders from Ultrasonic Pulse Velocity Test (ASTM C597)

Day	Cylinder	Distance L	Time (μsec)	Pulse Velocity (in./sec.)	Concrete Quality	Concrete Strength (psi)
	1	8	51.8	154440	Good	3430
7	2	8.14	53.3	152720	Good	3316
	3	7.996	49.9	160240	Very Good	3843
	4	8.145	48.7	167248	Very Good	4409
14	5	8.102	52.3	154914	Good	3462
	6	8.026	51.4	156148	Good	3547
	7	7.999	49.5	161596	Very Good	3946
28	8	8.085	51.8	156081	Good	3542
	9	8.039	50.8	158248	Very Good	3696

Table 3 shows the distances and times measured by the group using the UPV meter. Since the concrete cylinder containers were 8 inches long our cylinders had a length that was near 8 inches. The pulse velocity was calculated as shown below:

$$V = \frac{L}{Time * 10^{-6}}$$

$$V_{cylinder1} = \frac{8}{51.8 * 10^{-6}} = 154440 \frac{inches}{second}$$

Using Table C from the lab packet the concrete quality was noted in Table 3. For example, a pulse velocity of 157,480 inches per second correlates to a concrete quality of very good, while the pulse velocity for cylinder one which was calculated as a sample calculation was less than 157,480 but greater than 137,795 inches per second therefore its quality was good.

The concrete strength for each cylinder was calculated using the following equation:

$$f_c = 166.21 * e^{1.96*10^{-5}*V}$$

$$f_{c\ of\ cylinder1} = 166.21 * e^{1.96*10^{-5}*154440} = 3430\ psi$$

Table 4: Compressive Strengths of Concrete Cylinders from Rebound Hammer Test (ASTM C805)

Day	Cylinder	3 Top Side Recordings	3 Bottome Side Recordings	Rm (Mean Rebound Value)	Compressive Strength (MPa)	" " (psi)
7	1	12	15	12.5	8.333	
	1	13	12			
	1	12	13			1209
	2	15	19	14.25	9.500	
	2	11	15			
	2	14	13			1378
	3	16	18	16	10.667	
	3	15	18			
	3	12	15			1547
14	4	14	20	17.75	11.833	
	4	16	17			
	4	18	20			1716
	5	15	19	16	10.667	
	5	13	17			
	5	12	22			1547
	6	14	17	15.5	10.333	
	6	11	21			
	6	14	17			1499
28	7	12	20	15.25	10.167	
	7	12	17			
	7	11	20			1475
	8	13	21	17.25	11.500	
	8	20	20			
	8	13	16			1668
	9	12	19	13.75	9.167	
	9	10	20			
	9	11	13			1330

Table 4 shows the results from the rebound hammer test on all cylinders on both the top and bottom surfaces. The Mean Rebound Value was calculated by excluding the highest and lowest reading from the data set for each cylinder. For example, cylinder one had a data set of 12, 13, 12, 15, 12, and 13 therefore the readings of 15 and 12 (only excluding one of the highest and one of the lowest values only) are excluded when calculating the mean. The new data set was now 13, 12, 12, and 13. The average was then taken by summing up the values and then divided by the number of values summed.

$$Rm = \frac{\sum rebound\ values\ excluding\ the\ highest\ and\ lowest\ values}{4}$$

$$Rm = \frac{13 + 12 + 12 + 13}{4} = 12.5$$

The compressive strength was then calculated in Megapascals by interpolating table D in the lab packet as follows:

$$\sigma = \sigma_1 + (Rm - Rm_1) * \left(\frac{\sigma_2 - \sigma_1}{Rm_2 - Rm_1}\right) = Rm * \left(\frac{\sigma_2}{Rm_2}\right) = Rm * \left(\frac{17.2}{25.8}\right)$$

$$\sigma_{Cylinder1} = 12.5 * \left(\frac{17.2}{25.8}\right) = 8.333 \, MPa$$

The compressive strength was then converted into psi as follows:

$$\sigma_{cylinder1} = \frac{145.038 \, psi}{1 \, MPa} * \sigma_{cylinder1} = 8.333 \, MPa * 145.038 \left(\frac{psi}{MPa}\right) = 1209 \, psi$$

Table 5: Compressive Loads, Break Types, and Concrete Strength from Machine Crushing (ASTM C39)

Cylinder Number	Age (Days)	Compressive Load (lbs)	Break Type	Concrete Strength (psi)
1	7	59060	shear	4700
2	7	64790	cone	5156
3	7	63600	shear	5061
4	14	74270	shear	5910
5	14	71390	shear	5681
6	14	72780	shear	5792
7	28	77360	shear	6156
8	28	84280	cone and shear	6707
9	28	77740	shear	6186

Table 5 shows the measured compressive load and break type of each cylinder with the age of each cylinder. The most common break type seen for our group was shear. The concrete strength was calculated as shown below:

$$\sigma = \frac{F}{A}$$

$$\sigma_{cylinder1} = \frac{59060}{\pi * 2^2} = 4700 \, psi$$
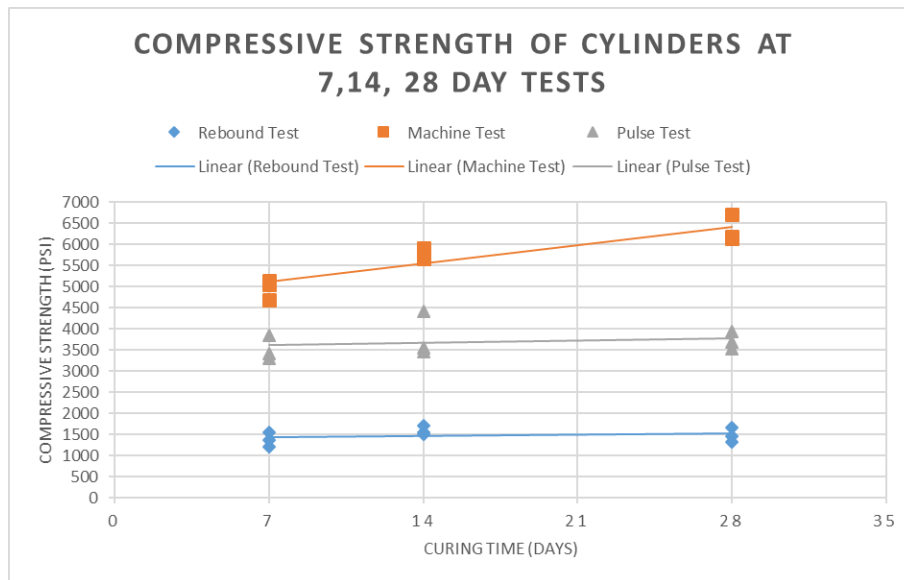
Analysis

Figure 1: Figure of Group 13's Data for the 3 Tests on Days 7, 14, and 28 (with a line of best fit for each of the 3 tests) *Data Points May Overlap due to them being relatively close to one and another*

Figure 1 shows our groups data collected for all the cylinders for all three tests on all three days. It can be seen on the figure that all data sets increase as curing time increased. This follows what should happen, since curing is used to increase concrete strength.
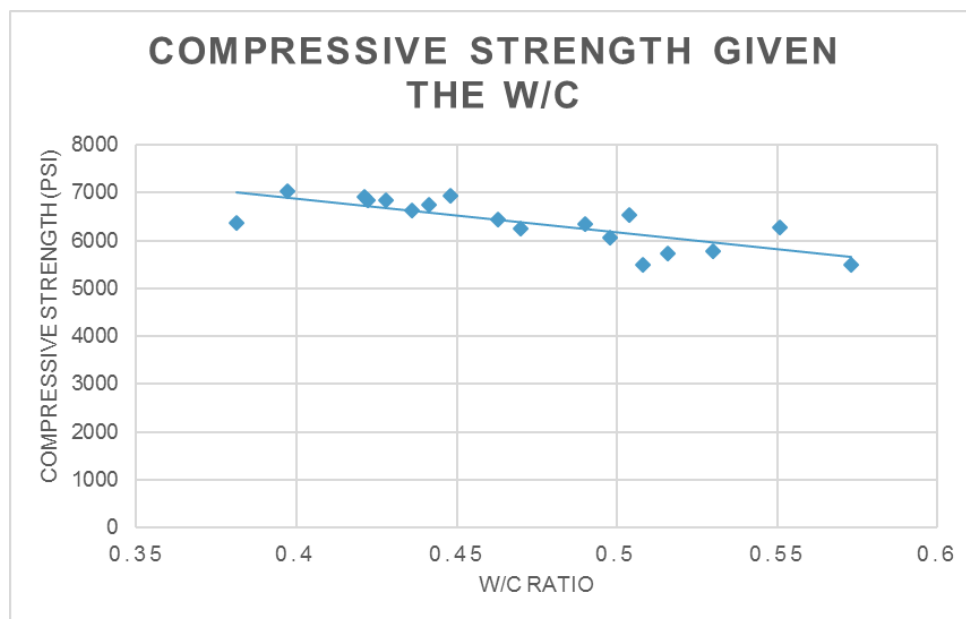

Figure 2: Figure of All Groups' (1-18's) Average Compressive Strength from Machine Compression on the 28th Day given their Calculated Water-Cement Ratio of their Respective Mixes (with a line of best fit)

Figure 2 shows relationship between the water-cement ratio and concrete compressive strength. Based on all the groups data the relationship follows the concept that more water decreases the overall compressive strength of the concrete.

1. What purpose do water, cement, coarse aggregate and fine aggregate play in concrete?
   a. Aggregates act as a filler in concrete, and thus improves the economy of the mix. The larger the aggregate, the more volume they take up. Fine aggregates take up less volume than the coarse aggregate, so it is necessary for there to be more aggregate. Aggregates have a greater volume stability than the cement paste, so it necessary to find the proper mix of fine and coarse to make up the mix. The cement paste acts as the glue to the mix, and holds everything together. Once the water is added, the cement to begin to harden in a process known as hydration. The water to cement ratio is the most critical factor in the production of concrete. Too much water reduces the concrete strength, while too little will make the concrete unworkable.

2. What does the slump indicate, both the value and the type?
   a. When we perform the slump test, we are measuring the workability of the concrete. After removing the slump cone, the difference between the top of the cone and the top of the concrete is the value that you are looking for. Looking back to Figure 1, it is apparent that there are different slumps depending on what happens when the cone is removed. Usually, values between 1" and 3" are classified as normal slump. This means that the concrete mix has the right consistency between you mix. If the difference is less than 1" than there is not enough water in the mix, and this would be classified as zero slump. Adversely, if the difference is more than 3", there is too much water and the mix needs to be adjusted. This could classify as a collapse slump depending on the severity of the fall. A shear slump would indicate that the mix lacks cohesion, and thus would be undesirable for the durability of the concrete.

3. What role does the air content play in the final concrete product?
   a. Air content plays a key role in the strength of the cured concrete, as well as the workability of fresh concrete. In fresh concrete, the air bubbles act as a lubricant and increases its workability and slump. Often, air entraining admixtures are added to increase the strength of the concrete, especially in freeze-thaw environments. A larger air content percentage would be necessary for continually wet-freeze-thaw. These "air pockets" provide space for water to expand upon freezing, rather than expanding and harming the durability of the concrete. It is important to test the air content of the mix before it is placed in the mold to cure in these situations.

4. What level of exposure would your concrete mix be suitable for, or is it not suitable for any exposure level? The maximum aggregate size is 3/8 inches. Explain you reasoning.
    a. Our air percentage was 4%, which would meet the requirement for mild exposure with a max aggregate size of 3/8". Even though the target value for mild exposure is 4.5%, specifications often allow -1% to +2% of the target value, and our value falls into this category.

5. Do you expect a change in the air content of freshly mixed concrete and the final in-place concrete? Explain your reasoning.
    a. I would expect a change in air content that would be less than plus or minus 1 to 2 percentage points. This would be due to the shrinkage of the concrete as it cures. These air pockets would be shrinking or getting larger as the concrete cures. Therefore, cracks occur because the concrete will literally pull itself apart.

6. Compare the 3 compressive strengths versus curing time curves (Figure 1). What could be the reasons for these differences? Which curve is the most accurate and why?
    a. The curve for the rebound hammer test went from around 1400 psi to a little over 1500 psi, while the Ultrasonic Pulse Velocity Test started around 3600 psi and ended around 3800 psi on the 28th day. The machine crushing test resulted in a curve that started around 5600 psi and on the 28th day ended around 6400 psi.
    b. The reason for the differences in these curves is a result of the applications of each of these tests and what these results mean. For example, the Ultrasonic Pulse Velocity Test is intended to find any defects in the concrete.
    c. The curve which is the most accurate is the Machine crushing test since that test is intended to measure the max force until the cylinder breaks and ultimately the max compressive strength of that test subject.

7. What is the common application of the rebound hammer test and ultrasonic pulse velocity test in practice? What are the advantages and disadvantages of each?
    a. The Rebound Hammer Test is used to assess the uniformity of concrete and assess the quality of concrete in relation to standard requirements.
        i. Advantages: Simple to use; no special experience is needed to conduct the test; establishes uniformity of properties; equipment is inexpensive and is readily available; a wide variety of concrete test hammers are available with an operational range ofM10 to M70; it is a nondestructive test.
        ii. Disadvantages: Evaluates only the local point and layer of masonry to which it is applied; no direct relationship to strength or deformation properties; unreliable for the detection of flaws; cleaning maintenance of probe and spring mechanism.
    b. The Ultrasonic Pulse Velocity test is used in practice to detect defects or deformations.

        i.   Advantages: It has high penetrating power which ensure very easy measurement even for the very deep concrete members; it is highly sensitive thus giving accurate results; easy to use for estimating the size, shape and nature of flaws in the concrete member; it is a nondestructive test.

       ii.   Disadvantages: Manual operation of the instrument requires careful attention by experienced technicians; if the surface is irregular it is difficult to estimate accurately the pulse velocity; test objects must be water resistant.

8. What are some factors that could affect the accuracy of the ultrasonic pulse velocity test?
    a. Smoothness of surface, irregular surface plane, path length, lateral dimension of the specimen tested, presence of reinforcement steel, and moisture content of the concrete can affect the accuracy of the test.

9. How does a UPV meter detect any flaws or defects present in the concrete?
    a. By doing multiple test concrete cylinders from the concrete batch a defect can be seen from a longer time for the beam to go through the cylinder, thus a slower speed calculated for a specific cylinder when compared to the others.

10. How does curing time affect the strength of concrete?
    a. As seen from the trend for all three curves for Figure 1 the longer the curing time the concrete strength of the cylinders where relatively higher than the previous test cylinders.

11. How is compressive strength calculated from the maximum load?
    a. $\sigma = \dfrac{F}{A}$

12. What is the most common break in the lab and in industry? Why?
    a. Lab: The most common break type in lab is shear, because of the machine settings and concrete mixes.
    b. Industry: The most common break type in industry is cone shear, because they use less sand in their mixes resulting in a different aggregate break line.

13. Provide any errors observed and respective recommendations to mixing and testing procedures.
    a. Errors observed in lab include one group member not tamping some cylinders and another not topping of the cylinder and smoothing the top of the cylinder.
    b. Some recommendations to mixing and testing procedures include to have a darker line at the one third and two third locations on all containers to show how much should be put in at a time and how far you need to tamp each layer;

to follow standard procedure for concrete cylinder filling and slump test with tamping into the previous layer slightly.