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Studying

The Effect of Adding Recycled concrete Aggregate on the Capability of Construction Blocks

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Studying The Effect of Adding Recycled Concrete Aggregate on the Capability of Construction Blocks

Prepared By:

Lana Mohammed Kaka Rash

Abstract: Due to the rise in global temperatures, more buildings require thermal insulation blocks. Since the use of thermal insulation concrete blocks and its production is a contributing factor to climate change then a new type of blocks is required. This paper investigates the effects of using recycled concrete aggregate concrete to create thermal insulation blocks on its strength. From a review of several sources, it was found that the use of recycled concrete in insulation blocks was poorly documented in the literature. Experimental procedures found that using recycled aggregate concrete yields strengths that are higher than blocks made with normal aggregate concrete.

Key Terms: Concrete blocks, Recycled aggregate concrete, Compressive strength, Strength development.

Contents

1. Introduction

The world is searching for new ways to make our way of life more sustainable. We know that planet Earth does not provide enough resources for us to consume continually forever, so we need new methods to reduce human consumption. Concrete can be said to be the main material for construction (EasyMix, 2018). However, it is not very sustainable because all the materials become useless once used, or so it was thought. Concrete from demolished structures does not have to be wasted. A new form of concrete, called recycled aggregate concrete (RAC), which utilizes the use of waste concrete as aggregate for the production of new concrete for projects. Concrete has the main ingredients of cement, sand, gravel and aggregate with the addition of additives if they are needed (Evangelista et al, 2018). Old concrete can be crushed to specific size and added to the mix to act as aggregate and replace the aggregate which is normally crushed stone. So, the concrete made would be more sustainable and has similar loading capacity to the normal aggregate concrete (NAC) and be used for similar parts of structures.

Masonry is a major part of construction and they shape many buildings and structures and the world today. There are many types of masonry in the form of blocks and bricks. Clay bricks were used to build structures until concrete blocks were produced. Concrete blocks provide a much better capability than clay bricks (Maria et al, 2015) and it can even be used to produce load bearing walls in small structures. The concrete blocks come in various forms and shapes but the most common type for walls is the 40cm x 20 cm x 20 cm block (Length x Height x Width) (Skat, 2020). These provide perfect capability and perform quite well in terms of capability; however, they do not perform well in terms of heat insulation of the building.

Concrete blocks have a high thermal transmission coefficient meaning that they transfer the heat into the internal part of the structure (Hao, 2017). These blocks are used in very hot and cold climates, so a replacement is necessary. Thermal insulation blocks (TIB) or sandwich blocks are special types of concrete blocks which are designed to have low thermal transmission coefficients so that they can be used for thermal protection of the buildings. These sandwich blocks can withstand loadings well and can be used in partition walls a9nd even load bearing walls for some structures (Wahab, 2019). The sandwich blocks utilize a layer of expanded polystyrene foam within the block itself to reduce the heat transmission. So, TIBs solve the issues of the bad thermal performance of concrete blocks (Al-Jabri et al, 2005). It consists of a small environmental barrier layer outside and the load bearing layer on the inside.

Due to protecting the environment, recycling and reusing materials is one of the methods to save the earth and keep the earth's materials. One of the most constructed materials is concrete that is used for many purposes in the engineering field. Also, it counts as one of the most destructive materials in the world because of this pollution that makes in the cement factories (Watts, 2020). To avoid being a pollution factor, we have to find a way to reduce the pollution by deducting the amount of time of working in cement factories which provide us concrete. The best thing to do at this time is using recycling concrete instead of fresh concrete.

The aim of this research is to study thermal insulation concrete block which is a construction material that has been used in engineering fields nowadays. The reason behind this topic is to innovate the block to make it be suitable with the environment of Kurdistan. The aim is to investigate the effects of using recycled aggregate concrete on the strength of the thermal insulation block.

2. Literature Review

(Zhu et al, 2014) A research that was conducted in China in 2014, studies the thermal properties of the recycled aggregate concrete (RAC) and recycled concrete blocks. This study considers four main factors, A) water unit consumption, B) the water cement Ratio, C) recycled coarse aggregate replacement ratio, D) recycled fine aggregate replacement ratio. The tests that were conducted during this research are thermal conductivity at various ratios of the recycled aggregate. Throughout the research, three different sizes of recycled aggregate concrete, 0-50mm 5-10mm and more than 10mm, were tested for their thermal conductivity. In addition to that, the heat transfer coefficient of the recycled concrete block was measured and it was found to be 0.93 W/m^2K which is an applicable value that meets the requirements. Moreover, the results of the thermal conductivity test, indicates that the recycled coarse aggregate has the highest effect on the thermal conductivity. From the given data it is apparent that the effect of factors A and B is minor which are water consumption and water–cement ratio; however, the replacement ratio of RAC has a great effect on both the thermal conductivity and the density of the concrete. The concrete has a higher thermal conductivity when the recycled coarse aggregate ratio is decreased, when the percentage of the aggregate is increasing to the right, the conductivity is dropping. However, there is a close correlation between the thermal conductivity and the density of the concrete and that is noticeable specifically in RAC, because the higher the thermal conductivity of the recycled concrete is, the higher the density of the concrete gets. However, the thermal conductivity was measured by using orthogonal tests; this is especially useful when the application to be studied has large data inputs.

(Zhang, 2018) is a research paper that explores the effect of the structure of the concrete block on its thermal conductivity. It looks at two types of blocks which are the traditional square shaped block and the new H-shaped block the authors propose to have a better thermal insulation capability. The source then goes on to use modeling equations to simulate the heat transfer through the block and express the thermal insulation capability mathematically. The authors have also carried out experiments to find the thermal performance of the block type. Tests were carried out on three different types of walls each with two different types of thicknesses, 240 mm and 190mm. The types 1 and 2 are the square shaped block walls while wall type 3 is the h-shaped concrete brick wall. They have found that the wall made with the H-shaped block has thermal resistance of over 0.5 m^2K/W which is higher than the other two types of block walls and the thermal inertia of the H-shaped block wall is also much higher than the other two which shows that in terms of thermal insulation, the H-shaped block provides a very good option. The H-shaped block's heat transfer behaves differently during the day than night. The increase during the day is due to higher surrounding temperature during the day and lower heat transfer coefficients during the night. The H-shaped block has a thermal coefficient of about 0.5 W/m^2K during the night and 4.5 W/m^2K during the day. The study done by this source is important to know which block shape is the most suitable for thermal performance. While the authors tell us the void percentage of the block is between 45% to 53%, however the research lacks any focus on the materials added to make the composite concrete block or the capability of it.

(He et al, 2014) is a research paper that studies the production of a concrete block by using recycled concrete coarse aggregate while having a high capacity and thermal insulation property. The main characteristics of the block are 310mm of thickness and containing 3-row holes, as mentioned in the paper the reason for containing holes in the design is because the holes lead to a distribution that can help to cut off the thermal bridge and leads to an increase in the thermal insulation. The design and dimensions were chosen to achieve a fair strength capacity with the maximum thermal resistance. This design can be beneficial and easy to use on-site; it can be used on drywalls due to its smooth surface texture. The inner holes can be filled with insulation material if required, in case no grouted concrete is used. The insulating layer is placed to help tear off the thermal bridge of the side and the second layer of insulation cuts off the thermal bridge of the inner transverse rib. The testing method used to measure the thermal resistance was heated flow meter. 8 block specimens were tested, as there were four different types of the block, and for each type, they used natural coarse aggregate and another block with recycled coarse aggregate. The four types contained concrete hollow brick, solid concrete brick and insulation material filled concrete hollow block. The outcome of this research has shown that the load-bearing thermal recycled concrete block has provided the best thermal resistance with, additionally, the research mentions that using recycled concrete rather than natural aggregate reduces the heat transfer coefficient by 9-20%. Moreover, using insulation material in concrete hollow blocks reduces the heat coefficient by 25.5%. However, this research was short of enough information about the bearing capacity and no tests were mentioned about it.

(Shi et al, 2019) investigates the thermal insulation capabilities of foamed concrete, concrete which has expanded polystyrene added to it. Expanded polystyrene is added to concrete to make it light weight, the density of the concrete is closer to 1000 kg/m^3 while the density of normal weight concrete is above 2000 kg/m^3. This type of concrete is quite capable; it takes 48 MPa after 28 days of curing. This study provides an alternative for producing thermal insulation concrete blocks. By adding the polystyrene to the concrete mix instead of having it in sheets embedded into the block. The addition of polystyrene makes the thermal conductivity of the concrete lower and it causes the coefficient to increase less with the increase in temperature. The type of concrete with the most polystyrene added starts with the least thermal conductivity at -10°C and increases to the least conductivity of the four types at 40°C. However, the thermal conductivity increases with the increase in the percentage volume of polystyrene added after a certain amount, this amount is 25% to 30% which provides the lowest thermal conductivity and therefore a better insulation. However, the concrete is porous, it has up to around 70% porosity and this might present challenges if it is used for thermal insulating concrete blocks in terms of capability of the block to withstand load.

(A.R et al, 2019) is a research paper which inspects the behavior of reinforced recycled aggregate concrete, and tests the uniaxial compressive, flexural, and splitting tensile strength of the concrete. The tests for compression and tension were performed on cylinders with 100mm in diameter and 200mm in length as required from the ASTM C39 (A.R, S, & Khan M.S, 2019) as for the flexural strength test the prisms specimen had a 100mm in width, 500mm in length and 100mm depth as mentioned in the ASTM C78. During the experiment the water to cement ratio and the percentage of the recycled aggregate were considered and the percentage of the recycled aggregate changed for different values in each specimen to notice their effect and behavior in the recycled aggregate concrete. The result of the compressive strength has shown that the natural aggregate has a higher strength compared to the recycled aggregate, and it is lowered by 11% for the RAC30, as it was the highest for the RAC00, and the reduction of the strength is 26% when the aggregate used is 100% recycled. As for the tensile and the flexural strength the same situation applies here as the recycled aggregate reduces the strength by 36% for RAC100 and the least reduction in 9.5% for RAC30. However, it is mentioned that the result for the flexure critic beams with recycled aggregate didn't seem to have a noticeable effect, but according to the data the stiffness is lowered in the recycled aggregate concrete compared to the natural aggregate in all of the flexural critical beams, in addition to that, the extent of cracks in the beams seems to be more in the recycled aggregate for the flexural critical beams.

(M. Sriraman et al, 2017) is a study looking into creating a lightweight polystyrene sandwich block. The paper examines the compressive strength of the lightweight blocks containing polystyrene. The blocks contain Ferro-cement, which encloses steel wire meshes; thermocol (polystyrene) was used as a filler material between the Ferro-cement to help the thermal insulation, and Portland cement of 53 grades with a specific gravity of 3.14, and fine aggregate (sand) was added to the mortar mixture. The tests were conducted on eight different specimens with various mesh pins, four blocks involve single meshes and the other four are in three web mesh, the various pins are in shapes of U M and V. The result for the compressive strength test shows that the WMU web mesh U-pin has the highest compressive strength which is 4.125 MPa, however it cannot be used as a structural component due to its low compressive strength which is less than 6 MPa and another complication with this paper was that each type of specimen was tested only twice, while a minimum of three specimen of each type should be tested according to (NRMCA, 2014)

(Liu et al, 2019) is research about the effect of using recycled concrete as aggregate on the compressive strength of the block itself and on the strength of the wall made with it. The experimental work consists of three types of blocks which consists of 0%, 50% and 100% recycled concrete replacement of natural aggregates. The recycled concrete was crushed to be around the same sieve size of the natural aggregate. They have found that using recycled concrete slightly decreases the capability of the concrete block. However, the overall effect on the compressive strength of the wall made with the masonry unit is very small. The wall made of concrete blocks that contained natural aggregates failed at a compressive stress of 8 MPa while the wall made with concrete blocks containing recycled had a compressive strength of 7.5 MPa. From this data it can be deducted that the compressive strength of the block itself has a very small effect on the strength of the masonry structures made out of it. This source is useful because the authors have shown that the when used in masonry work, the recycled aggregate concrete will have a small reducing effect on the strength of the structures made. The authors have not looked at the thermal insulation capabilities of the blocks made with recycled concrete.

(Dafalla et al, 2019) This study conducted in Japan 2019, observes the influence of the density and thickness on concrete blocks by designing it with several manner of insulation with polystyrene and testing the efficiency of it. The polystyrene was tested for six months observing its thermal conductivity and the weather factors. Two chambers were designed for the polystyrene boards to be tested inside, each had four walls of concrete walls, each with a thickness of 20cm and the dimension of the block was 1m height, 1m length, and 1m width. They both had a wooden roof and the difference between the two blocks was one had an insulation using polystyrene and the other block didn't contain it. As for the density two different types of polystyrene were used, a roof-mate and a wall-mate, having an average density of 35.5Kg/m^3 and 27Kg/m^3 respectively. The results showed that the wall-mate polystyrene with the more density has more thermal conductivity compared to the roof-mated polystyrene. Furthermore, Thermal conductivity between an exposed (six months) and non-exposed polystyrene board had a difference of 0.5%. Moreover, the insulated block and a non-insulated block were compared with their temperature range over 24 hours; the insulated block had a range of less than 5ºC, while the non-insulated block's range was between 8ºC to 20ºC. Two types of polystyrene were used, a dense and non-dense roof-mates, as each type had a 4cm and a 5cm of thickness, according to the results, the denser roof-mate had a lower thermal conductivity, in addition to that, and the difference of 1cm had an effect of 0.75°C. However, to be able to use polystyrene as insulation material, testing the thickness and the density is not sufficient.

(Gua et al, 2018) another article about the use of recycled aggregate in masonry work, the article is mostly about the life cycle and the sustainability of the masonry; however, it contains information about the strength of the masonry. The strength of blocks made with recycled concrete aggregate has a lower compressive strength and shear strength, however this difference is not very large. The compressive strength for a normal concrete block was 9.86 MPa while it was 9.38 MPa for recycled aggregate concrete; the shear strength was 1.59 MPa for normal concrete while it was 1.55 MPa for recycled aggregate concrete. Even on the plant trials, a normal aggregate concrete block only has a reduced strength of about 7% which is a considerable alternative when you also compare the sustainability of the production of the two types of blocks. Different walls were made with the types of concrete blocks. The compressive strength of the blocks when used in making walls, high strength mortar was used and their results that the ultimate strength of the walls are similar and in one of the cases, the strength of the recycled concrete aggregate block wall is higher than the normal aggregate wall. The results show that the compressive strength of concrete blocks made with recycled concrete aggregate is similar, although slightly reduced, to the strength of the blocks made with normal aggregates. This together with the other literature reviews shows that recycled concrete aggregate is promising in terms of capability and it can withstand similar stresses.

(Sariisik et al, 2012) is about a new production process for insulation blocks composed of lightweight concrete containing pumice aggregate. This research paper inspects the property of lightweight thermal concrete blocks, and it consists of the data that comes from examining this type of concrete block. A single lightweight thermal insulation concrete block with (200 width*400length*200height) mm dimension was produced, and the polystyrene was used between the concrete parts as a sandwich. All aggregates that are usually used in lightweight blocks were used to have this production, and then the product cured for 28 days. After doing this process for making this material, the product was ready for testing and examination to get the data of its properties. The value of deviation after 28 days from the plane was 0.150mm, and the deviation of the flange from the plain was 0.40mm; the compressive strength of the product was 2.99N/mm^2; dry density value was 562kg/m^2; water absorption coefficient by capillaries was 20.63 g/mm^2 sn$^{0.5}$; sound absorption value of the masonry unit was 60 (dB); thermal conductivity coefficient was 0.33 W/mK; initial shear strength value was 0.471 N/mm^2. The research shows that dry density and compressive strength have a proportional relationship that means increasing each one makes the other one increase. To illustrate, when dry density is 540kg/cubic meter the thermal conductivity is nearly 0.315 W/mK, but then the dry density was increased to 600kg/cubic meter the thermal conductivity is increased to 0,35W/mK. Also, the dry density has the same relationship with thermal conductivity. The researchers tested the relationship between these two properties, so the result is proportional relationship. To explain, when dry density is 540kg/cubic meter, the compressive strength is nearly 2.7 MPa, but then the dry density is increased to 600kg/cubic meter, the compressive strength is increased to nearly 3.4 MPa. The information attained in this research is important since the authors have shown a relationship between dry density and strength of concrete.

The literature review shows that the use of recycled concrete is investigated along with the strength of the normal and thermal insulation blocks. However, the use of recycled aggregate concrete is poorly documented in the literature. So, this study aims to provide an analysis of the effect of recycled aggregate concrete on the capability of thermal insulation blocks and a basis for more sustainable production of masonry materials.

3. Experimental Procedures

The experimental techniques that will be used are laid out in this section.

3.1. Creating molds for the samples

The forms or molds are needed to shape the sample blocks and hold them until the concrete hardens. The molds have the same inside dimensions as the block, be easy to reuse and provide a good seal. The chosen material was wood because it was available and easy to cut, the form for one block consisted of 4 sides and a bottom piece. The top was left to allow the concrete to dry and to allow for the ease of removal, the forms can be seen in figure 1. The following are the materials used to hold the forms together:

- Screws were used to hold the sides of the forms together, this provided strength to withstand the force used during compaction while it was easier to remove than using nails. The screws allowed the forms to be taken apart every time and put back together easily. This meant that only 4 forms were needed and they were reused to make new samples.
- Pumped foam sealant was used in the corners to provide a good seal and prevent concrete or water from leaking out of the mold. These provided some strength in holding the sides of the form together as well. Also, they could be easily removed after use so the wood forms can be stuck together using screws and then sealed again.
- A single loop of steel cables was tied around the forms to provide strength and prevent them from coming apart in case the screws failed to hold during compaction.

<u>Figure 1:</u> The forms used to create the samples on the right and the inside of a form before casting on the left.

3.2. Materials

3.2.1. Concrete mixing proportions

The dimensions of a block were 0.2 x 0.2 x 0.4 (H x W x L) which gave a volume of 0.016 m^3. The foam that was used had a thickness of 60 mm that with it inside the block it meant that this volume of concrete (0.0048 m^3) did not need to be accounted for. This gave the volume of concrete needed for each block to be 0.0112 m^3. The mix ratio of cement, sand and aggregate was 1:3:5 which meant for every part of cement, there were 3 parts sand and 5 parts aggregate. The following formula was used to find the volume of cement:

$$V = 0.67(C + S + A)$$
Where $S = 3C$ and $A = 5C$
$$V = 0.67\ (9C)$$

V is the volume of concrete, C is the volume of cement, S is the volume of sand and A is the volume of aggregate.

From the formula above, the volume of cement was calculated which was then used to calculate the volumes of sand, aggregate and water. The water-cement ratio used was 0.3 which meant that the volume of water used was 30% of the volume of cement. The volumes were then used to calculate the masses of the materials needed for a normal block, shown in table 1.

Table 1: The material requirements for a normal block.

Materials	Volume [m^3]	Density [kg/m^3]	Mass [kg]
Cement	0.0019	1500	2.79
Sand	0.0056	1600	8.92
Aggregate	0.0093	1600	14.86
Water	0.00056	1000	0.56

The aggregate was replaced for the blocks of type B, C and D. Table 2 shows the replacement crushed and the new aggregate for the recycled concrete block types. The recycled aggregate was old concrete samples and blocks which were broken down into small pieces and then those pieces were crushed into the size required. The aggregate was sieved through 10 mm sieve, so the size of particles used were 10 mm or smaller. The cruising was carried out by hand using a hammer which was a time-consuming process.

Table 2: Aggregate replacement amounts for recycled concrete blocks.			
Aggregate Replacement [%]	**Mass of aggregate [kg]**	**Mass of RAC [kg]**	**Mass of normal aggregate [kg]**
25	15	3.75	11.25
50		7.5	7.5
100		15	0

We can see on table 2, the total mass was rounded to a whole number. This was done to allow for errors and waste during casting, adding a small amount extra so that each mix of concrete meets the volume demand it needs to fill. The design proportions for the blocks of each type are shown in table 3.

Table 3: Design amounts of the materials for one block of the different block types.					
Block Type	**Cement [kg]**	**Sand [kg]**	**Aggregate [kg]**	**RAC [kg]**	**Water [L]**
A	3	9	15	0	1
B	3	9	11.25	3.75	1
C	3	9	7.5	7.5	1
D	3	9	0	15	1

3.2.2. Casting procedure

The following procedure is for making one block, which was repeated for all the samples that were created:

1. Use lubricant oil (car engine oil) to coat the insides of a form well. Ensure the form is held together securely.
2. Place the foam inside the form, ensure that it is in contact with the bottom and
3. Acquire the materials required for 1 block, mix ratios given in table 3.
4. Dry mix the cement, sand and aggregate well until the cement is evenly distributed giving the mix a grey color. Wear gloves and eye protection.
5. Create a mount of the mixed materials like shown in figure 2 with hole in the middle. Fill the pond with as much of the water as it takes.

<u>Figure 2:</u> Mixing a batch of concrete.

6. Slowly add the dry materials from the side to the pond, do not rush this so water does not leak and wash the cement away.
7. Once the pond is filled with wet concrete, mix the wet concrete well and gradually add the remaining water if any. Ensure there is an even mix, this can be seen by the homogenous color of the concrete.
8. When the concrete is ready, start pouring it into the form. Ensure the foam is secured in the middle and it does not get tilted or moved.
9. Add the concrete in 3 layers, compact the concrete using a rod at first and then using flat tip heavy compactors. Ensure there is good compaction in the corners and in between the teeth of the foam.
10. Once the final layer is added and compacted, leave the concrete in the form for one day to allow it to harden.
11. After one day, remove the form and leave the block to dry if there is moisture left. Clearly label each block on multiple sides, write the curing time and the type. Leave the blocks submerged in a water bath for the duration of the curing time.
12. Re-attach the form for the next sample.

3.3. Testing

3.3.1. Compressive testing and dimension measurement procedure

The Following steps will be taken for each block to find its strength and other properties:

1. After the curing time is past, remove the blocks from water and allow it to air dry completely. Wear gloves and the block may be heavy for one person, so lift them in pairs.

2. Once dry, measure and record the dimensions of the block (height, width and length). Make sure that you get an accurate measurement.
3. Weigh the block and record its mass.
4. Use a compressive testing machine to find the compressive force required for the block to fail.

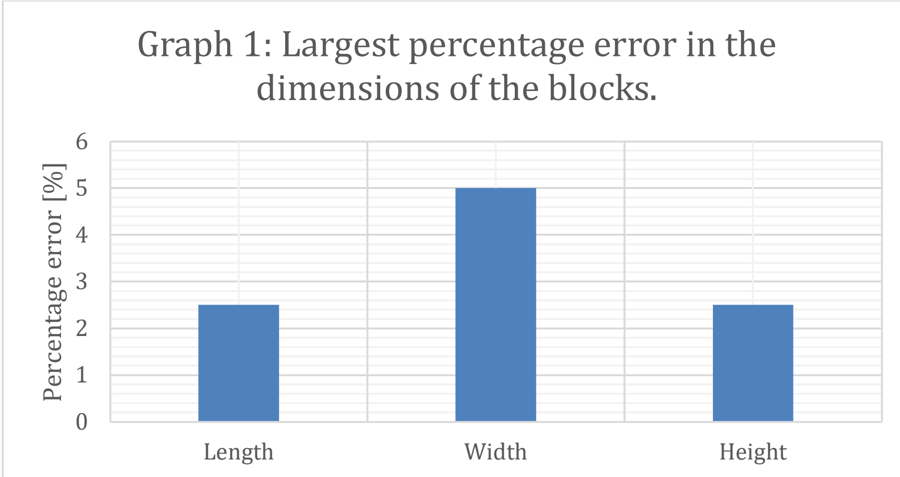
4. Results

4.1. Dimensions of samples

Table 4 shows the actual dimensions of the produced for this experiment in terms of length, width and height for all curing times and the types of blocks. Graph 1 shows the highest percentage errors in each dimension on a bar chart.

Table 4: The true dimensions of each block.

Block Type	Dimensions [mm]	Curing Time [days]		
		7	14	28
A	Length	397	390	399
	Width	203	200	203
	Height	204	202	200
B	Length	405	405	405
	Width	206	200	210
	Height	205	200	200
C	Length	400	393	395
	Width	203	201	195
	Height	200	200	200
D	Length	398	397	400
	Width	200	200	200
	Height	202	200	199

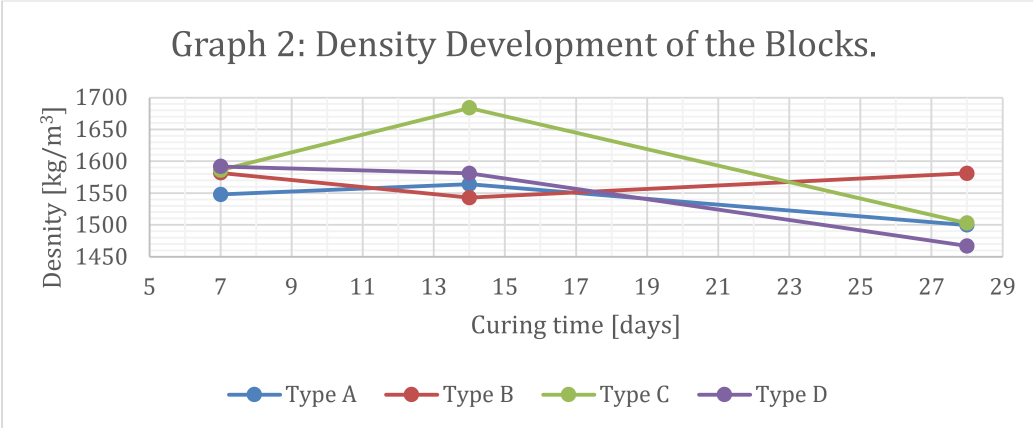


4.2. Properties of samples

Table 5 shows the masses and densities of the blocks. The volume was calculated using the true dimensions of the samples and not their theoretical values, this was done to get an accurate density of the block as a whole. An important fact to consider is that the densities shown are of the block as a unit, which consists of concrete and the foam, and not density of the concrete or the foam separately. Graph 2 visualizes the density development over the curing time.

Table 5: Properties of the blocks including mass, volume and Density.

Block Type	Properties	Curing Time [days]		
		7	14	28
A	Mass [kg]	25.45	24.65	24.3
	Volume [m^3]	0.0164	0.0158	0.0162
	Density [kg/m^3]	1548	1564	1500
B	Mass [kg]	27.05	25	26.9
	Volume [m^3]	0.0171	0.0162	0.0170
	Density [kg/m^3]	1582	1543	1581
C	Mass [kg]	25.75	26.6	23.15
	Volume [m^3]	0.0162	0.0158	0.0154
	Density [kg/m^3]	1586	1684	1503
D	Mass [kg]	25.6	25.1	23.35
	Volume [m^3]	0.0161	0.0159	0.0159
	Density [kg/m^3]	1592	1581	1467

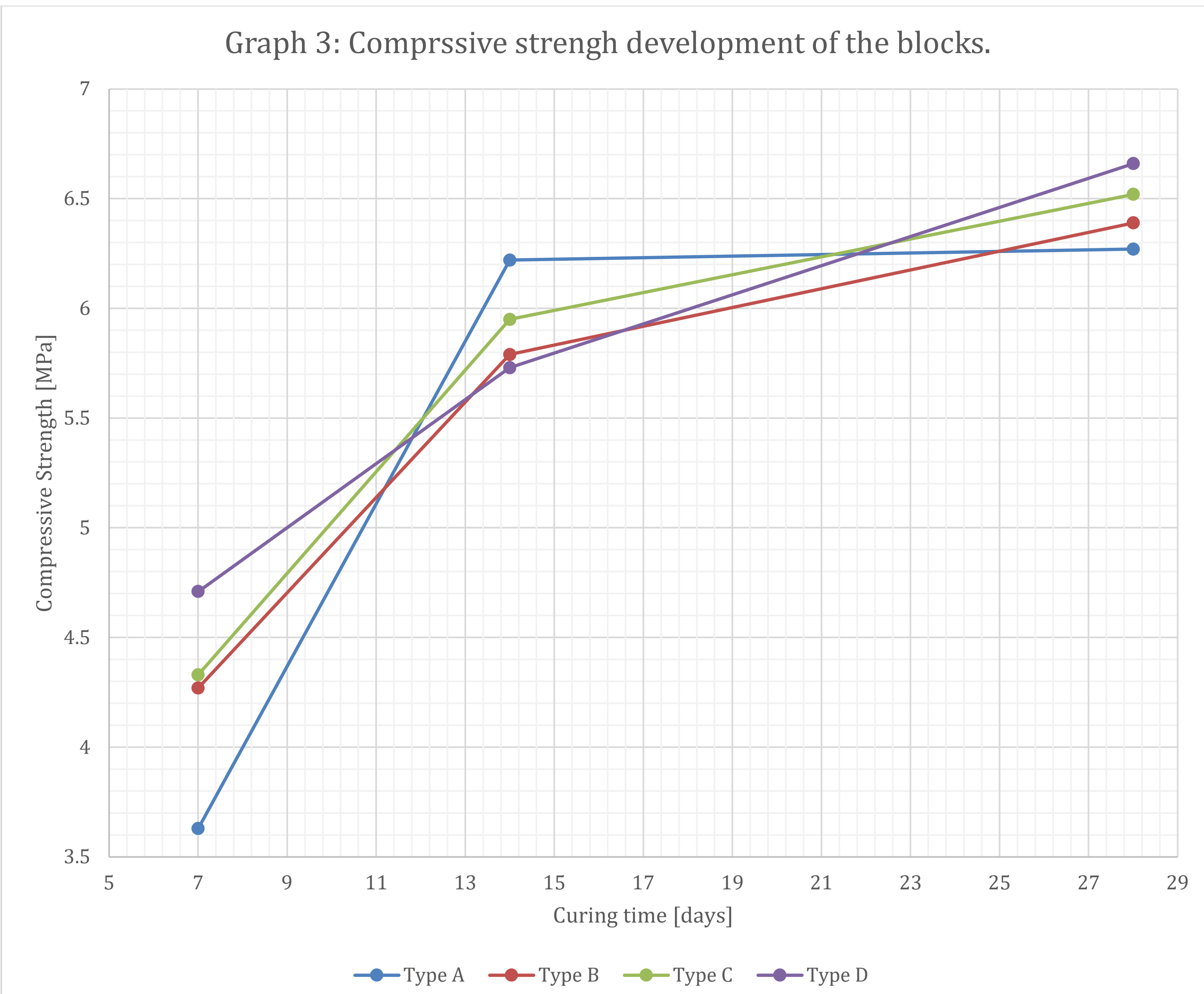


4.3. Compressive strength testing

The results for the compressive testing are shown on table 6. The device used only provided the force used to bring the concrete block to failure, then this force was divided by the area of the part that was in contact with the device. The area for the 7 days of curing was found by multiplying 0.3 m by the true width of the block due to the device having a circular geometry, see figure 3, this was fixed for 14 and 28 days by adding two metal plates on top and under the block (shown on figure 3) so the true widths and lengths can be used.

Table 6: Compressive strength of samples				
Block Type	**Compressive Strength**	**Curing Time [days]**		
		7	**14**	**28**
A	**Force [kN]**	292.46	484.8	508
	Area [m^2]	0.0609	0.0780	0.0810
	Strength [MPa]	3.63	6.22	6.27
B	**Force [kN]**	356.39	469.16	543.11
	Area [m^2]	0.0618	0.0810	0.0851
	Strength [MPa]	4.27	5.79	6.39
C	**Force [kN]**	351.48	470	502
	Area [m^2]	0.0609	0.0790	0.0770
	Strength [MPa]	4.33	5.95	6.52
D	**Force [kN]**	375	455	533
	Area [m^2]	0.06	0.0794	0.0800
	Strength [MPa]	4.71	5.73	6.66

<u>Figure 3:</u> The circular machine tool (left) and the plates added above and below the block (right).



5. Discussion and Analysis

The accuracy of the results is important to have reliable outputs from this investigation, the dimensions of the blocks play a major role on the compressive strength of the blocks, they have effects on the thermal conductivity too since thinner blocks will transmit more heat. Table 4 shows the dimensions of each block that were created in the lab, the dimensions were not equivalent for each block because the forms that were created were wooden forms, and they were tightened by bolt, steel cables and sealant foam. The forms were reused four times each in order to create the samples for the experiment.

Every time they were taken apart and reassembled, the sources of error could be the misplacing of bolts or it could be because of the concrete and sealant sticking to the edges of the forms which changed dimensions of the blocks. The deviations were not very high in general with the highest recorded percentage deviations from the true dimensions being 2.5 % for the length, 2.5% for the height and 5% for the width as we can see from graph 1. The maximum difference from a dimension is 10 mm and this is very low compared to the actual length, width and height. An improvement to this would be creating new forms for every sample made, however this will be less economical and with the reusing of the forms having an accuracy of 95% (or 10 mm) makes it a reliable technique to use.

Table 5 shows the properties of the block include mass, volume and density. The results immediately show that the density of the thermal insulation blocks is around 1500 kg/m^3 (100 kg/m^3) which is less than the density of the normal concrete blocks that have density more than 2000 kg/m^3 although the sample blocks made for this experiment do not have hollow sections in the concrete parts. The difference in the density of the blocks is obviously due to the foam in the middle which has a very low density of 27 kg/m^3 and 30 kg/m^3, this reduces the density of the block as a whole. The density development of the blocks is shown on graph 2, we can see that the density of blocks varies differently during curing time up to 28 days.

The density of the blocks of type A decrease with type to the lowest density of 1500 kg/m^3 after 28 days, however the type B blocks have density decrease to lowest at 14 days (1543 kg/m^3) then increase to the highest at 28 days of curing which had a value of 1581 kg/m^3. Type C blocks have the highest density at 14 days of curing 1684 kg/m^3, however this value is very high and it does not agree with the values of density for type C block or any other types. It is unclear what general trend of the density development is from the results acquired from this experiment. Further investigation will allow more clarification of this; however, it seems that the density decreases with time. This could be due to the deviations in dimensions or it would also be due to the fact that the blocks were not fully dry at the time of measurement, due to lack of time in the labs as a result of covid-19 pandemic, the blocks could not be allowed to dry completely and they were dried at different rates. So, some were wetter than others. This might have led to errors in the mass which directly affects the density.

The compressive strengths measured are shown on table 6 with graph 3 showing the strength development over time. We can see that the strength of the blocks increases overtime, however the strengths at 7 days of curing are much lower, which is expected, but it does not fit into the trend of the data. This is a direct effect of the geometry of the testing machine, the compressing area in the machine was circular instead of rectangular and it was small so it could not cover the entire top surface area of the block, this is shown in figure 7. To overcome this problem, the length of each block was assumed to be 300 mm (0.3 m), the diameter of the circular ring, in the calculations for the 7 days results. However, the true widths of each block were used to calculate the surface area, this meant a more accurate strength could be found. Using the device in this way meant that the path of failure of the blocks were determined before testing, the compressive force of the machine only acted on a certain area which caused all the cracks and failure to be concentrated on the edges of the circular disk on the block, affecting the compressive strength and reducing them.

The testing was improved upon for the 14 days and the 28 days by adding 20 mm thick metal plates (40 cm x 20 cm) above and beneath the blocks (shown on figure 7). Adding the plates ensured that the force from the device was distributed evenly across the block and the true width and length of the blocks can be used to calculate the compressive strength. We can see on graph 3 that the compressive strength has a more believable trend between 14 days and 28 days.

Type A blocks have the lowest compressive strength at 7 and 28 days (3.63 MPa and 6.27 MPa respectively) while they have the largest compressive strength at 14 days of curing which is 6.22 MPa. On the other hand, type D block has a reverse strength development trend of the type A, it has the highest strengths at 7 and 28 days while it has the least strength at the 14 days curing time. The results of the compressive strength for 28 days are used as base strength ratings of the blocks. The blocks used for normal purposes here in Iraqi Kurdistan are either for partition walls in buildings or for load bearing walls in buildings up to 3 stories. The required strength of the blocks used are between 6 MPa and 8 MPa which all block types met.

The results of this experiment show that the use of recycled aggregate concrete (RAC) in thermal insulation blocks will not result in compromising on strength of the block. The type D blocks, which contain 100% RAC have the highest compressive strength of 6.66 MPa, even higher than the type A which was made with normal aggregate concrete. The results suggest an improvement of strength with the recycled aggregate which makes more of an appealing choice. Making blocks with 100% recycled concrete will increase the sustainability of the building technology. This could be due to the recycled aggregate containing filler material which decreases void ratio of the block and therefore make it more capable, thus increasing strength. More research is required to further support this claim.

6. Conclusion

Samples were created to test the compressive strength of the blocks, the results found in this experimental study suggest the following conclusions:

- Reusing the forms for experiments like this might result in error in dimensions of up Celsius to 5%, however it is still more economical and sustainable than using fresh mold for each sample.
- The density of thermal insulation sandwich blocks is lower than the density of the normal blocks due to the addition of the foam layer. Also, the density of the blocks decreases overtime while curing.
- Blocks made with recycled aggregate concrete yield compressive strengths which match the strength requirements for buildings, the results suggest further that the blocks made with 100% RAC yield higher compressive strengths than the blocks made without any recycled concrete.

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