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Research Article

EXPERIMENTAL STUDY OF LIGHTWEIGHT PROJECTILES PENETRATION IN CONCRETE WITH WASTE STEEL SHAVINGS AND RICE HUSK ASH

***Hamid Reza Hasanpour Berijani[1] and Seyed Shahab Emamzadeh[2]**
[1]*Passive Defense Research Institute, Imam Hussain University*
[2]*Passive Defense Research Institute, Imam Hussain University*
**Author for Correspondence*

ABSTRACT
In this research, a composition of rice husk ash and steel chips has proposed for construction of anti-impact and cost effective concrete. Rice husk ash is inexpensive and is rich in silica and it is obtained from waste products. It can replace a portion of the cement. Silica in the rice husk ash is important for concrete compressive strength. Also, to increase tensile strength, the concrete has been reinforced by steel shavings which are inexpensive. Gas gun tests have been done on 36 concrete slabs specimens which contain different percentages of rice husk ash and steel shavings. The water to cementations materials ratio of 0.57 were used. The result has shown that, by 10% replacement of cement by RHA, and adding steel shavings of 1% of total weight, the highest strength could be obtained. Furthermore, penetration depth has been reduced by 17% compared to no steel shavings and no husk ash specimen.

Keywords: *Steel Chips, Rice Husk Ash, Impact, Penetration, Projectile*

INTRODUCTION
Concrete structures used in defense applications should be retrofitted against impact loads such as loads caused by projectile impact. The impact and penetration-resistant concrete is a concrete with high resistance to projectiles penetration that generally consists of components such as aggregates, binder materials, water and reinforcement materials.
There are abundant aggregates in nature, the amount of water has little impact on the price of the concrete and the remaining options are binder and reinforcement materials, so by using appropriate and inexpensive materials we can achieve a cost effective and resistant concrete.
Cement is one of the binder materials used in concrete that plays a major role on the cost of concrete. One of the cement replacement materials is rice husk ash which contains a high percentage of silica. So far, several studies have been done on the effects of rice husk ash on the strength of normal concretes [1], and high-strength concretes [2]. In these studies, it has been affirmed that rice husk ash enhances the compressive strength of concrete.
Sensate, (2006) investigated the compressive strength of cylindrical concrete specimens enriched by 10 and 20 percent of rice husk ash. He used two types of rice husk ash as mineral admixture and tested specimens with water to (cement + ash) ratio of 0.32, 0.4 and 0.5 until the age of 91 days. He approved that the strength of 7 days, 28 days and 91 days old specimens have been increased compared to the specimen without ash.
On the other hand, steel shavings are one of the materials reinforcing tensile strength of the concrete which maintain the integrity of the concrete and prevent the growth of tension cracks.
Luo *et al.,* (2000) used steel shavings in high performance concrete and found that the resistance of cube concrete specimens to high-velocity projectiles impacts shows a significant increase compared to the concrete without fibers. Ong *et al.,* (1999) have studied the effects of low-velocity projectiles impacts using falling weight test on concrete slabs reinforced by steel fibers.
The results showed that by adding 0.5, 1 and 2% of steel fibers into the slabs with a thickness of 20 cm, the amount of energy required to break up the slab has been increased up to 31 percent. However, expensive and scarce chips were used in this project.

Teng *et al.*, (2008) have studied the effect of high-velocity projectiles on fiber concrete. They simulated the behavior of fiber concrete by developing numerical models and defining attrition elements. The results were in good agreement with the results of tests.

Reviewing the previous studies indicates that one of the problems in producing impact and penetration resistant concrete is that such concretes are not cost-effective.

Therefore, in this study in order to produce cheaper impact and penetration resistant concrete, steel chips that can be obtained from industrial wastes are used to increase the tensile strength of concrete. Moreover, the rice husk ash which is an agricultural waste is used instead of a portion of cement to increase the compressive strength of the concrete.

Initially, concrete specimens containing chips are prepared and after measuring their compressive strength, penetration rate of the desired projectile is theatrically calculated using equation proposed by the National Defense Committee of America (NDRC). Then, specimens are placed in gas gun machine and are faced to direct impact of desired projectiles. To ensure accuracy of results, theoretical and experimental penetration depth will be compared.

The Experimental Equations for the Penetration Depth of Projectile into Concrete

The effect of projectile depends on the hardness or softness of the target object. Projectiles can cause partial or general structural damages.

According to Figure 1, partial damages include destruction of the front surface of the concrete in front of the target, destruction of the back surface of the concrete and eventually pitting or creating a tunnel between destruction of the front and the back of the target.

General damages include bending deformations and macroscopic cracking which depends on the size and the material of the target.

The amount of general and partial damages depends on various factors such as velocity, mass, geometry and material of the projectile as well as thickness and hardness of the target. Experimental observations show that the majority of concrete targets are partially damaged due to their high hardness at the time of collision.

The National Defense Committee of America has proposed the following equation for measuring the penetration depth of the projectile into the concrete target (x) (Vossoughi *et al.*, 2007).

$$\frac{x}{d}=\begin{cases} 2\sqrt{G} & G\leq 1.0 \quad or \quad \frac{x}{d}\leq 2 \\ 1+G & G\geq 1.0 \quad or \quad \frac{x}{d}\geq 2 \end{cases} \qquad G=\frac{3.8\times 10^{-5} NMV^{1.8}}{f_c^{0.5} d^{2.8}} \tag{1}$$

Where, M is the mass of the projectile, d is the diameter of the projectile, V is the velocity of the projectile before collision, f_c is the concrete compressive strength, N is the ratio of the projectile nose shape (Beds:0.72, round:1 and sharp:1.14) and $\frac{x}{d}$ is the ratio of penetration of the projectile tip to the projectile diameter. Here, all parameters are in SI units. This committee has also proposed an equation to the minimum thickness required to have a non-pitted target (h_s).

$$\frac{h_s}{d}=\begin{cases} 7.91(\frac{x}{d})-5.06(\frac{x}{d}) & \frac{x}{d}\leq 0.65 \\ 2.12+1.36(\frac{x}{d}) & 0.65<\frac{x}{d}\leq 11.75 \end{cases} \tag{2}$$

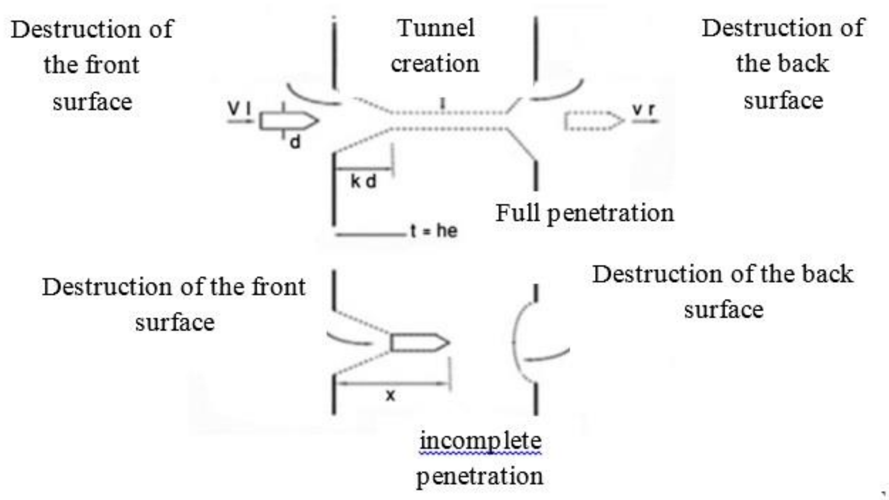

Figure 1: Full and Incomplete Penetration of the Projectile into the Concrete [6]; kd= the Depth of Penetration into the Front Surface, d = the Diameter of the Projectile, he= the Thickness of the Specimen and Penetration Depth in the Case of Full Penetration, VI= the Inlet Velocity of the Projectile, Vr = the Exit Velocity of the Projectile

Characteristics of the Projectile and Gas Gun

Lightweight steel projectiles were used in gas gun test. As shown in Figure 2, the length of the projectile is equal to 2.54 cm and its diameter is equal to 7.62 mm and its tip is a cone with vertex angle of 45 degrees. By heat treating bullets, their hardness has been greatly increased and the mass of bullet with its sabot is considered as 9.5 g.

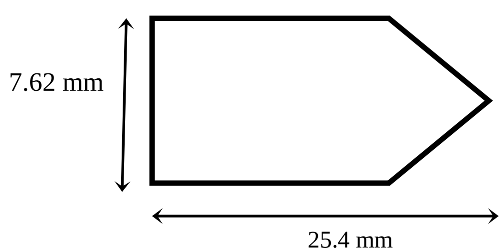

Figure 2: The Bullet and Sabot

A gas gun was used to fire the bullet. This device has several parts, such as gas supply, gas tank, diaphragm and solenoid valves, the projectile placement, long steel tube to allow passage of the projectile, speedometer system, etc. In Figure 3, the components of a gas gun are shown. Compressed nitrogen gas is used for low-velocity projectiles and compressed helium gas is used for high-velocity projectiles.

There is a diaphragm valve in front of the gas tank which is located right behind the projectile placement. In Figure 4, diaphragm valve and the projectile placement are shown. This valve works based on the diaphragm that is placed inside it. By opening the supply, gas is stored in tank and its pressure is gradually increased to a certain pressure in which the diaphragm is ruptured and the pressure stored behind the diaphragm causes the projectile to be fired. In Figure 5 the diaphragm used in the valve is shown before and after the shot.

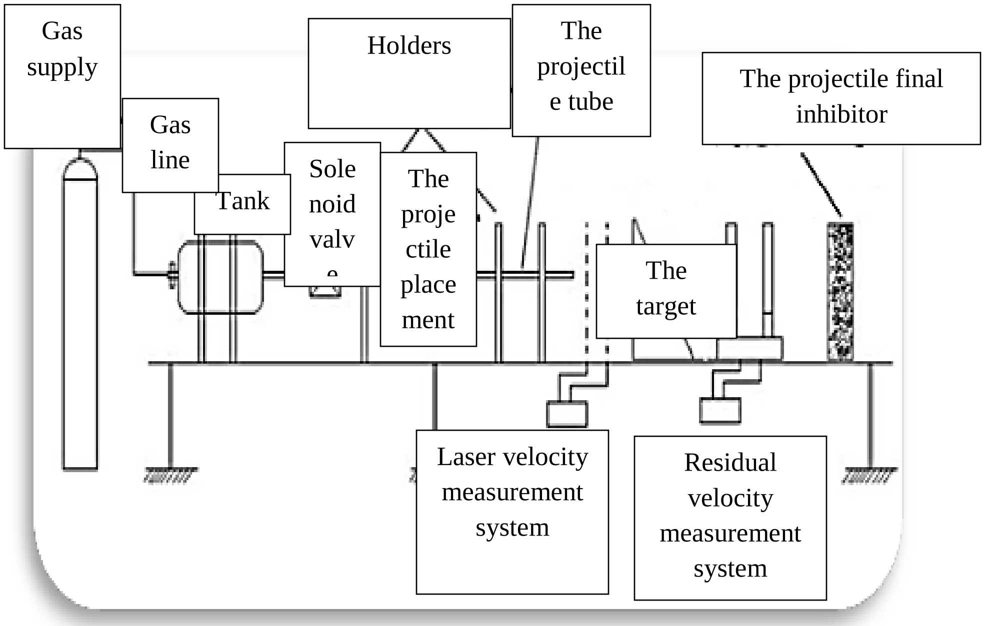

Figure 3: The Components of Gas Gun

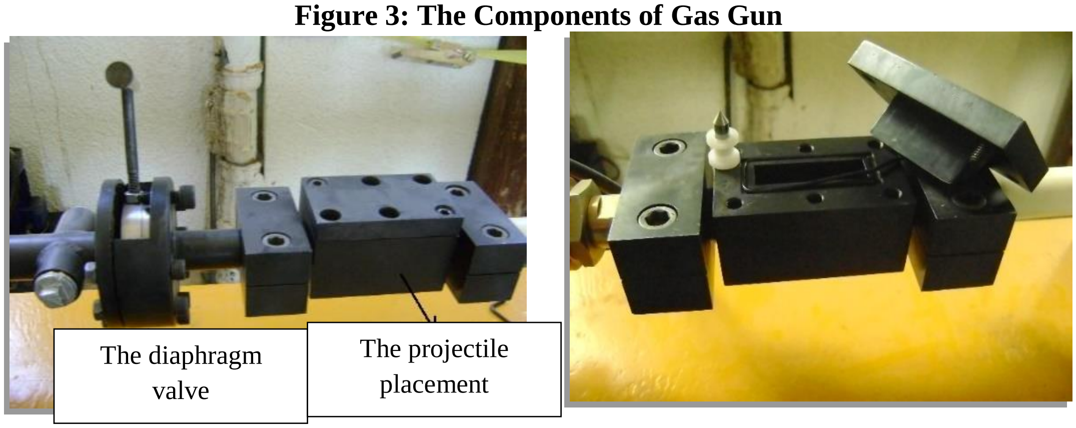

Figure 4: Diaphragm Valve and Projectile Placement in Gas Gun

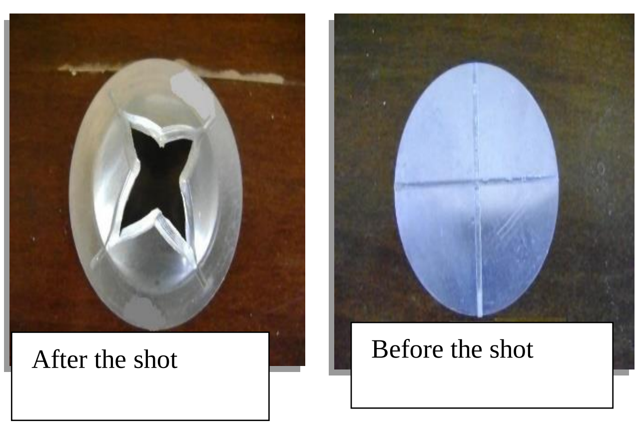

Figure 5: The Diaphragm Before and After the Shot

There is a very long tube in front of the tank that the projectile is placed inside it. A ruptured diaphragm or electrical connection in a solenoid valve causes that the tank gas pressure be discharged at once behind the projectile and fire it. The final velocity of the projectile leaving the end of the tube is a function of the length of the tube, the tank gas pressure, expansion coefficient of used gas, type of the diaphragm and mass of the projectile. Furthermore, there is a laser system to measure the velocity before the target that measures the projectile velocity after firing and just before hitting the target. This velocity measuring system includes a device which has two laser sensors at the front and rear of itself that when the projectile passes through them, projectile motion time is measured. Due to the constant distance between the two sensors, the velocity is measured and shown.
Target specimens are placed in front of the device called fixture and are quite restrained. By closuring the bolt, four edges of the fixture are sealed and surround the specimen tightly and do not allow it to move. Therefore, in terms of boundary conditions we can be sure that around the piece is constrained in all directions. For this purpose and given the specific dimensions of concrete targets, a fixture as shown in Figure 6 was designed and made.

Figure 6: The Fixture Made for Holding the Target

The projectile exit velocity that is called the residual velocity is also measured by a laser system. But because the projectile ricochets after passing through the target or due to occurrence of plugging, the system often cannot measure the residual velocity and, moreover, the possibility of laser residual velocity measuring system damage due to the projectile's impact is very high. To overcome these problems and on the other hand because of the importance of the residual velocity parameter, another system is used to measure velocity. The performance of this system, similar to laser system, is to measure the velocity of the projectile before hitting the target. But because the projectile ricochets after passing through the target, the projectile coverage should be a plate so that if the projectile is deflected, the system can detect its passage. Also the system should be installed in such a way to minimize its risk of getting damaged. Given all the items mentioned above, aluminum foil plates are used to detect the passage of the projectile. Two aluminum foil plates with a distance of 3 mm from each other were installed on a set and each of these plates were connected to the electric circuit using a wire. At a distance of 28 cm from these plates two additional aluminum foils were installed exactly the same as the previous foils and they were also connected to the circuit. In this case when the projectile is fired and the circuit is closed, the residual velocity measurement system after that the projectile passed through the target, as soon as the projectile hits two first foils, connects them and the flow is established in the circuit and the circuit timer begins to record time. When the projectile connects two second foils together, the timer circuit stops and the recorded time is actually the time required to the projectile to travel the distance between the two sets of foils. Because this distance and the projectile transit time are specific, the residual velocity of the projectile is obtained. Figure 7 shows the residual velocity system set after the target placement. Moreover, the position of foils in the residual velocity system set as well as the position of specimen in the fixture are shown in this figure.

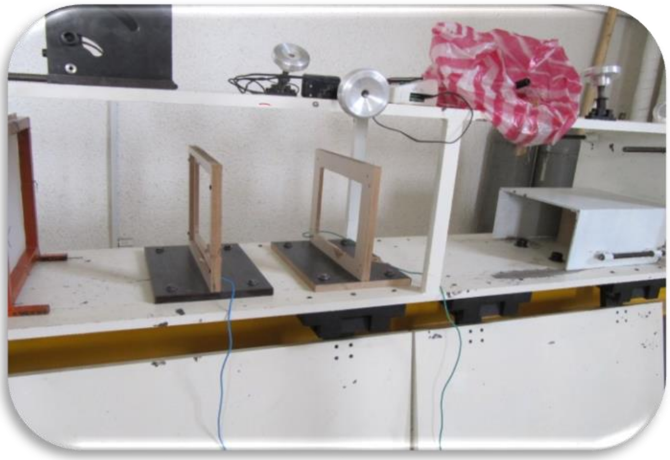

Figure 7: The Residual Velocity System Set and Foils Inside Wooden Frames

In these tests the velocity of the projectile is high and all the operations are done within a few milliseconds. Means that the process is not completely controlled. Therefore, anything is possible like the bullet ricochet and stray from its path especially after the projectile passage. Therefore, these areas should be completely covered at the time of firing. A final inhibitor should be placed at the end of the gas gun such as ballistic dough, a bag full of sand, pieces of wood or any other suitable device, to restrain the projectile and prevent any possible damage to the set. However, given that the projectile velocity is very high, so controlling what happens during penetration of the projectile into the target is very difficult and is only possible using very advanced cameras with high frame. In this study, the use of multiple cameras was not possible and the only parameters extracted from ballistic test on specimens included initial velocity, velocity of the projectile after passing through the target (residual velocity) and the projectile energy absorption by the target.

MATERIALS AND METHODS

Methodology and Analysis

Determining Effective Percentage of Steel Chips

To determine the effective percentage of steel chips, cylindrical specimens of concrete were made based on mix design shown in Table 1 and were put under uniaxial compressive with a combination of different percentages of steel chips. For this purpose, 18 cylindrical specimens were made and tested at 7,14 and 28 days old. The results are shown in Figure 2.

Table 1: The Concrete Mix Design

Materials	Kg/m^3
Mazandaran Cement Type 2	393
Drinking Water	227
Gravel from Mazandaran Mines	695
Sand from Mazandaran Mines	918
w/c	0.57

According to Figure 8, the results show that if the weight percentage of steel chips is increased, up to 1%, compressive strength is increased and for more than 1 percent, the strength will be reduced. On the one hand, given that the chips are metal waste and are smeared with fat that may be not completely gone by washing, and on the other hand, chips may prevent full adherence of aggregates with cement due to being broad, and for these reasons if the amount of chips in the concrete mix is increased the strength is reduced. According to above results, 0.5 and 1 percent of steel chips were selected to reinforce concrete specimens. Selected specimens were combined with 5, 10 and 15% of the rice husk ash replaced a portion of cement and were tested.

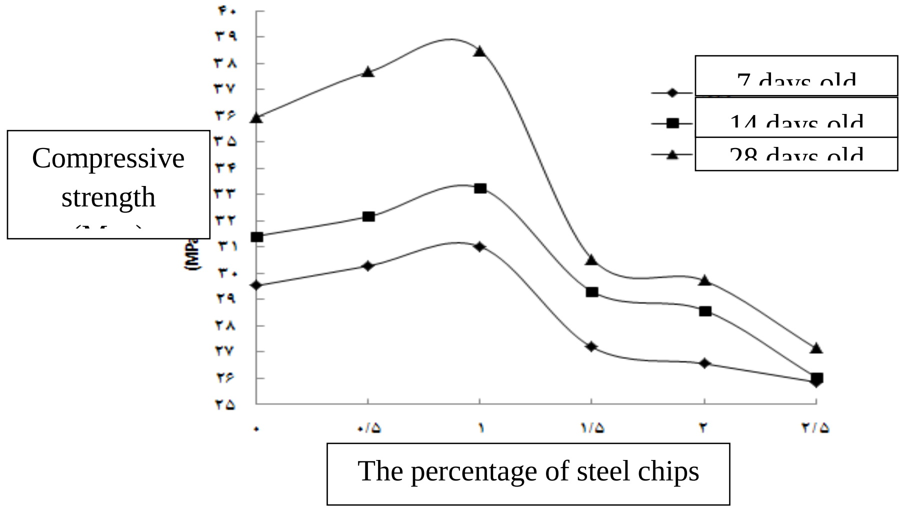

Figure 8: Comparison of Compressive Strength of Specimens Containing Different Amounts of Steel Chips

According to Table 1, materials were prepared in the laboratory scale and based on the compositions presented in Table 2, three cylindrical specimens were made for each combination for compressive strength test and four mosaic specimens were made for bullet penetration test for 28 days old concrete.

Table 2: Concrete Mix Design with Steel Chips and Rice Husk Ash

Mix Design	**W/c**	**Water (kg)**	**Cement (kg)**	**Gravel Fine) Grain(kg)**	**Sand (Large Grain) (kg)**	**Steel Chips (kg)**	**Rice Husk Ash (kg)**	**Slump (cm)**	**Mix Percentages**
P	0.57	7.64	13.20	30.83	23.34	0	0	4	No Waste Material
PA	0.57	7.64	12.54	30.83	23.34	0.38	0.66	4	0.5% Steel Chips+5% Rice Husk Ash
PB	0.57	7.64	11.88	30.83	23.34	0.38	1.32	4	0.5% Steel Chips+10% Rice Husk Ash
PC	0.57	7.64	11.22	30.83	23.34	0.38	1.98	4	0.5% Steel Chips+15% Rice Husk Ash
PD	0.57	7.64	12.54	30.83	23.34	0.76	0.66	4	1% Steel Chips+5% Rice Husk Ash
PE	0.57	7.64	11.88	30.83	23.34	0.76	1.32	4	1% steel chips+10% rice husk ash
PF	0.57	7.64	11.22	30.83	23.34	0.76	1.98	4	1% Steel Chips+15% Rice Husk Ash

Grading fine materials (with a diameter less than 6.35 mm) were closed to the normal grading according to Iranian National Regulation Standards and then were used to make specimens. After preparing concrete and pouring it into the molds, they were kept at room temperature for 24 hours and then were extruded and stored in a pond of cold water at a temperature of approximately 25 ° C for 28 days, then they were extracted from the pond and weighting operation and compressive strength tests were immediately performed and records can be seen in Table 3.

Table 3: The Results of the Compressive Strength of Specimens Containing Steel Shavings and Rice Husk Ash

Mix Design	Mix Percentage	The Average Compressive Strength (MPa)
P	No Waste Material	30
PA	0.5% Steel Chips+5% Rice Husk Ash	30
PB	0.5% Steel Chips+10% Rice Husk Ash	33
PC	0.5% Steel Chips+15% Rice Husk Ash	37
PD	1% Steel Chips+5% Rice Husk Ash	33
PE	1% Steel Chips+10% Rice Husk Ash	38
PF	1% Steel Chips+15% Rice Husk Ash	40

The Projectile Penetration Test

In the projectile penetration test, to measure damages and cracks growth, concrete specimens were made with different concrete mix designs in the mosaic form with dimensions of 5 × 30 × 30 cm. Three specimens of each mix design and a total of 18 specimens were prepared. All specimens were 28 days old during the penetration test, and were cured in a pond of cold water with a temperature of 20 ° C. The results of the projectile penetration test using gas gun for the average of three specimens of each mix design are shown in Table 4.

PA: 0.5% steel chips+5% rice husk ash; PB: 0.5% steel chips+10% rice husk ash; PC: 0.5% steel chips+15% rice husk ash; PD: 1% steel chips+5% rice husk ash; PE: 1% steel chips+10% rice husk ash; PF: 1% steel chips+15% rice husk ash.

In PA combination, all three specimens were totally pitted and the projectile went out the other side with the residual velocity. Three stages of penetrating into the concrete target were clear. In NDRC equation, minimum thickness for having a non-pitted target in this composition is equal to 7.89 cm while the thickness of the specimen is equal to 5 cm, so it is clear that the specimen is pitted when the projectile hits it as it was happened.

In PB combination, two bullets were stopped inside the specimens no. 1 and 2, and three bullets passed through specimen no. 3 but fell behind the specimen with zero velocity. According to the bullets average inlet velocity and the average compressive strength of concrete in this composition, and according to the NDRC method, minimum thickness of 5.12 cm is required to have a non-pitted concrete specimen while the specimen with the thickness of 5 cm is not pitted which is because of steel chips. In PC combination, the bullet was stopped inside the specimen's no. 1 and 3, and passed through specimen no. 2 with zero velocity.

According to the bullets average inlet velocity and the average compressive strength of the concrete in this composition, minimum thickness of 5.27 cm is required to have a non-pitted concrete specimen while the specimen with the thickness of 5 cm is not pitted which is because of steel chips. In PD combination, the bullet was stopped inside the specimen's no. 1 and 2, and passed through specimen no. 3. According to the bullets average inlet velocity and the average compressive strength of the concrete in this composition, minimum thickness of 5.83 cm is required to have a non-pitted concrete specimen while the specimen with the thickness of 5 cm is not pitted which is because of steel chips.

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Table 4: The Results of Projectile Penetration Test Using Gas Gun

Specimen	Non-Pitting Thickness (h_s)	Impact Velocity (m/s)	The Projectile Residual Velocity (m/s)	Impact Energy (j)	Residual Energy (j)	Energy Absorption Percentage	$\left(\frac{x}{d}\right)_{NDRC}$	$\left(\frac{x}{d}\right)_{LAB}$	The Difference Between Two Methods (%)
PA	7.89	542	72	1395	25	98.23	6.39	-	-
PB	5.12	354	0	595	0	100	3.38	3.19	5.6
PC	5.27	337	0	540	0	100	3.88	3.25	16.24
PD	5.83	395	10	741	5	99.94	4.07	3.37	17.20
PE	5.76	378	67.1	679	0.01	96.85	3.51	2.90	17.38
PF	5.62	414	67.1	814	0.10	97.37	3.87	-	-

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In PE combination, the bullet was totally penetrated into the specimen no. 1, and stopped inside the specimen no. 2 and its tip has been seen in the back of the specimen and was incompletely penetrated into the specimen no. 3. According to the bullets average inlet velocity and the average compressive strength of the concrete in this composition, minimum thickness of 5.76 cm is required to have a non-pitted concrete specimen while the specimen with the thickness of 5 cm is not pitted which is because of steel chips. Specimens made by PF combination were all crushed after the impact of the bullet and the projectile passed through them. The reason was that the average thickness of the specimens was 4.2 cm and they were completely fixed inside the holder. So they had a little mobility which exacerbated the impact of the projectile hit and destructed the specimen. In Figure 9 an example of the crack surface of one of the specimens is shown.

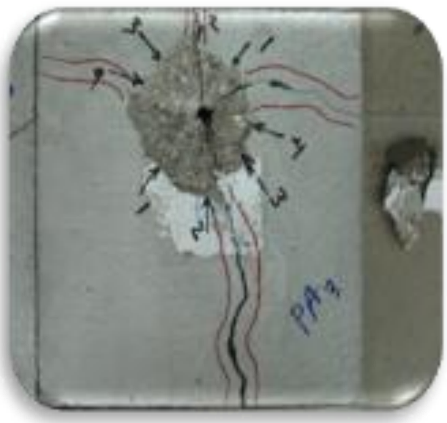

Figure 9: An Example of Concrete Destruction Surface

To determine the best combination, it is necessary that the penetration depth ratio of the NDRC equation be compared to the experimental penetration depth ratio for each composition. In NDRC equation it is assumed that no waste materials are added to the concrete. However, in the NDRC equation, the compressive strength is considered equal to the compressive strength of test specimens containing waste materials. Therefore, the difference between two depths for each specimen represents the impact of adding waste materials. Difference percentage of the penetration depth ratio are obtained from the equation 3 and the values are shown in Table 5.

$$\text{The difference percentage } = \frac{\left(\frac{x}{d}\right)_{NDRC} - \left(\frac{x}{d}\right)_{LAB}}{\left(\frac{x}{d}\right)_{NDRC}} \times 100 \qquad (3)$$

Table 5: Comparison of Experimental Results and NDRC Equation Results

Specimen	Experimental Penetration Depth	Penetration Depth Ratio from NDRC Equation	Difference Percentage
PA	At the impact place, specimen is collapsed	6.39	-
PB	3.19	3.38	5.6%
PC	3.25	3.88	16.23%
PD	3.37	4.07	17.19%
PE	2.90	3.51	17.38%

By investigating results, it is indicated that PE combination, which contains 15 percent ash and 1% chips, had the greatest impact compared to the specimen with the same strength and its penetration depth reduction is about 17.38%.

Conclusion

In the present study we have tried to make an impact and penetration resistant concrete by adding waste materials such as rice husk ash and steel shavings into the concrete mix design and also in this research it has been attempted to achieve an optimum combination of waste materials in concrete to reach the highest impact resistance. Therefore, the results show that replacing 10% rice husk ash instead of cement and adding steel shavings of 1% of the total weight, the penetration is reduced by 17%. Due to the low price of waste materials the obtained design in addition to the high impact resistance, is also cost-effective.

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