PREDICTION OF COMPRESSIVE STRENGTH OF RECYCLED AGGREGATE CONCRETE USING SOFT COMPUTING

A Dissertation

Submitted in the Partial Fulfillment for the Requirement for the Award of the Degree of

Master of Technology

Structural Engineering

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ABSTRACT

It is not possible to predict the strength and other concrete properties solely based on the properties and proportions of the mix components. Therefore, mixes are designed on an empirical basis, often with the help of trial mixes. The objective of the mix design is to assure that the product has specified properties in both the fresh and hardened state. The material obtained immediately upon mixing of the various concrete ingredients is called fresh concrete, while hardened concrete results when the cement hydration process has advanced sufficiently to give the material mechanical strength. Concrete that is batched and mixed in a plant and then transported by truck in its fresh, or plastic, state to the construction site for final placement is called ready-mixed concrete. Code-writing organizations, such as the American Society for Testing and Materials, the American Concrete Institute (ACI), and the American Association of State Highway and Transportation Officials (AASHTO), have published detailed specifications and recommendations for measuring, mixing, transporting, placing, curing, and testing concrete. A proper mix design assures that the concrete mix is well proportioned

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CHAPTER – 1

INTRODUCTION

Concrete

A composite material that consists essentially of a binding medium, such as a mixture of portland cement and water, within which are embedded particles or fragments of aggregate, usually a combination of fine and coarse aggregate. Concrete is by far the most versatile and most widely used construction material worldwide. It can be engineered to satisfy a wide range of performance specifications, unlike other building materials, such as natural stone or steel, which generally have to be used. Because the tensile strength of concrete is much lower than its compressive strength, it is typically reinforced with steel bars, in which case it is known as reinforced concrete.

Materials

A composite material is made up of various constituents. The properties and characteristics of the composite are functions of the constituent materials' properties as well as the various mix proportions. Before discussing the properties of the composite, it is necessary to discuss those of the individual constituents as well as the effects of the mix proportions and methods of production.

Cement

There are many different kinds of cements. In concrete, the most commonly used is portland cement, hydraulic cement which sets and hardens by chemical reaction with water and is capable of doing so under water. Cement is the “glue” that binds the concrete ingredients together and is instrumental for the strength of the composite. Although cements and concrete have been around for thousands of years, modern portland cement was invented in 1824 by Joseph Aspdin of Leeds, England. The name derives from its resemblance of the natural building stone quarried in Portland, England.

Portland cement is made up primarily of four mineral components (tri calcium silicate, di calcium silicate, tri calcium aluminate, and tetra calcium aluminoferrite), each of which has its own hydration characteristics. By changing the relative proportions of these components, cement manufacturers can control the properties of the product.

The primary product of cement hydration is a complex and poorly crystalline calcium-silicatehydroxide gel (or CSH) [1]. A secondary product of hydration is calcium hydroxide, a highly crystalline material. A category of siliceous materials known as pozzolans have little or no cementitious value, but in finely divided form and in the presence of moisture will react chemically with calcium hydroxide to form additional CSH. This secondary hydration process has a generally beneficial effect on the final concrete properties. Examples of pozzolans are fly ash, ground granulated blast-furnace slag, and micro silica or silica fume.

The American Society for Testing and Materials (ASTM) defines five types of cement, specifying for each the mineral composition and chemical and physical characteristics such as fineness. The most common cement is Type I. Type III cement is used if more rapid strength development is required. The other types are characterized by either lower heat of hydration or better sulfate resistance than that of Type I cement.

Aggregate

The aggregate is a granular material, such as sand, gravel, crushed stone or iron-blast furnace slag. It is graded by passing it through a set of sieves with progressively smaller mesh sizes. All material that passes through sieve #4 [0.187 in. (4.75 mm) openings] is conventionally referred to as fine aggregate or sand, while all material that is retained on the #4 sieve is referred to as coarse aggregate, gravel, or stone. By carefully grading the material and selecting an optimal particle size distribution, a maximum packing density can be achieved, where the smaller particles fill the void spaces between the larger particles. Such dense packing minimizes the amount of cement paste needed and generally leads to improved mechanical and durability properties of the concrete.

The aggregate constitutes typically 75% of the concrete volume, or more, and therefore its properties largely determine the properties of the concrete. For the concrete to be of good quality, the aggregate has to be strong and durable and free of silts, organic matter, oils, and sugars. Otherwise, it should be washed prior to use, because any of these impurities may slow or prevent the cement from hydrating or reduce the bond between the cement paste and the aggregate particles.

Admixtures

While aggregate, cement, and water are the main ingredients of concrete, there are a large number of mineral and chemical admixtures that may be added to the concrete. The four most common admixtures will be discussed.

1. Air-entraining agents are chemicals that are added to concrete to improve its freeze–thaw resistance. Concrete typically contains a large number of pores of different sizes, which may be partially filled with water. If the concrete is subjected to freezing temperatures, this water expands when forming ice crystals and can easily fracture the cement matrix, causing damage that increases with each freeze–thaw cycle. If the air voids created by the air-entraining agent are of the right

size and average spacing, they give the freezing water enough space to expand, thereby avoiding the damaging internal stresses.

2. Water-reducing admixtures, also known as super plasticizers, are chemicals that lower the viscosity of concrete in its liquid state, typically by creating electrostatic surface charges on the cement and very fine aggregate particles. This causes the particles to repel each other, thereby increasing the mix flow ability, which allows the use of less water in the mix design and results in increased strength and durability of the concrete.

3. Retarding admixtures delay the setting time, which may be necessary in situations where delays in the placement of concrete can be expected. Accelerators shorten the period needed to initiate cement hydration—for example, in emergency repair situations that call for the very rapid development of strength or rigidity.

4. Color pigments in powder or liquid form may be added to the concrete mix to produce colored concrete. These are usually used with white portland cement to attain their full coloring potential.

Reinforcing steels

Because of concrete's relatively low tensile strength, it is typically reinforced with steel bars (Fig. 1). These bars are produced in standard sizes. In the United States, the identification number of a reinforcing bar refers to the nominal diameter expressed in eighths of an inch. For example, a number 6 bar has a diameter of 6 /8 = 0.75 inch = 0.01905 m. The available bar sizes range in general from 2 to 18. Reinforcing steel usually has nominal yield strength of 1071.478 kg/mm.2 (414 MPa). To improve the bond strength between the bars and the concrete, the bars are fabricated with surface deformations or ribs. The relatively high cost of steel mandates its sparing use. This means that the concrete is usually assigned the task of resisting compressive forces, while the steel carries primarily the tensile forces [2]. The alkalinity of the cement paste generally provides sufficient protection of the steel against corrosion. However, corrosion protection is often breached, for example, in highway bridge decks with continuous pore structure or traffic-induced cracks that permit the deicing chemicals used in winter to penetrate the protective concrete cover. Additional protective measures may be necessary, such as using epoxy coatings on the bars, noncorrosive steels, or non metallic reinforcement (for example, fiber-reinforced polymers).

Other important concrete terminology can be defined. A mixture of cement and water is called cement paste. Cement paste plus fine aggregate is called mortar or concrete matrix. Mortar plus coarse aggregate constitutes concrete. Concrete reinforced with steel or other high-strength material is known as reinforced concrete.

Figure 1: Workers placing and vibrating concrete on a bridge deck including epoxy-coated reinforcing steel. (Portland Cement Association) [1]

PRODUCTION OF CONCRETE

The properties of the end product depend not only on the various constituent materials listed above but also on the way they are proportioned and mixed, as well as on the methods of placing and curing the composite.

Mix design

It is not possible to predict the strength and other concrete properties solely based on the properties and proportions of the mix components. Therefore, mixes are designed on an empirical basis, often with the help of trial mixes. The objective of the mix design is to assure that the product has specified properties in both the fresh and hardened state. The most important mix design variable is the weight ratio between water and cement, referred to as the w/c ratio. There is a theoretical minimum amount of water needed for the cement to completely hydrate, which can be determined using the equations of hydration chemistry. Any excess water creates pores which, together with any air-filled pores, do not contribute to the material strength. The result is a drastic decrease in strength as a function of increasing the w/c ratio. On the other hand, too low w/c ratios cause poor workability of the concrete. For practical reasons, the w/c ratio typically varies between 0.4 and 0.6. The other important mix design variables are the cement-to-aggregate ratio and theafine-to-coarse aggregate ratio. Also, the maximum aggregate size is of importance. And since cement is the most expensive bulk ingredient, the mix design will generally aim at the least amount of cement necessary to achieve the design objectives.

Construction practice

The material obtained immediately upon mixing of the various concrete ingredients is called fresh concrete, while hardened concrete results when the cement hydration process has advanced sufficiently to give the material mechanical strength. Concrete that is batched and mixed in a plant and then transported by truck in its fresh, or plastic, state to the construction site for final placement is called ready-mixed concrete. If the resulting structure or highway pavement, for example, remains in place after placement, the concrete is referred to as cast-in-place concrete, whether mixed on-site or off-site. Precast concrete refers to any structure or component that is produced at one site, typically in a precasting plant, and then transported in its hardened state to its final destination. The controlled environment of a precasting plant generally permits higher quality control of the product than is possible with cast-in-place concrete produced at a construction site.

Code-writing organizations, such as the American Society for Testing and Materials, the American Concrete Institute (ACI), and the American Association of State Highway and Transportation Officials (AASHTO), have published detailed specifications and recommendations for measuring, mixing, transporting, placing, curing, and testing concrete. A proper mix design assures that the concrete mix is well proportioned. The mixing time should be sufficient to assure a uniform mixture. When placing the concrete, care should be taken to avoid segregation. For example, if dropped too far, the heavy or big aggregate particles can settle and lighter mix components, such as water, tend to rise. The concrete is conveyed from the mixing truck to its final destination in dump buckets by cableways or cranes or by pumping through pipelines. In modern high-rise building construction, concrete has been pumped as high as a thousand feet (330 m).

During placement, large amounts of air are entrapped in the mix, which lowers the strength of the hardened concrete. Much of the air is removed by compaction, which is achieved by either immersing high-frequency vibrators into the fresh concrete or attaching them to the outside faces of the formwork (Fig. 1). Care must be taken to avoid excessive vibration; otherwise the heavy aggregate particles settle down and the light mixing water rises to the surface.

For underwater construction, the concrete is placed in a large metal tube, called a tremie, with a hopper at the top and a valve arrangement at the submerged end. For so-called shotcrete applications such as tunnel linings and swimming pools, the concrete mixture is blown under high pressure through a nozzle directly into place to form the desired surface [3].

Before the concrete sets and hardens, it is relatively easy to give its exposed surfaces the desired finish. Surfaces cast against forms can be given various textures by using form liners or treating the surfaces after forms are removed. Hardened surfaces can be textured by grinding, chipping, bush-hammering, or sandblasting.

Curing

Once the concrete has been placed and compacted, it is critical that none of the mixing water needed for cement hydration is lost. This is the objective of curing. For example, in hot or dry weather large exposed surfaces will lose water by evaporation. This can be avoided by covering such surfaces with sheets of plastic or canvas or by periodically spraying them with water. In precast concrete plants, concrete elements are often steam-cured, because the simultaneous application of hot steam and pressure accelerates the hydration process, which permits high turnover rates for the formwork installations.

Quality control

To assure that the finished material has the specified properties, quality assurance and quality control procedures need to be implemented. From a public safety viewpoint, strength is the most important property. To assure adequate strength, such as determining the time of safe formwork removal, concrete batches are sampled by casting test cylinders at the same time and place as the structure being built. These cylinders are then tested by accredited laboratories to determine their strength. If the in-situ strength of existing structures needs to be evaluated, concrete cores may be drilled from selected parts of the structure and tested in the laboratory. There are also nondestructive test methods available to determine various properties of hardened concrete.

PROPERTIES OF FRESH CONCRETE

The most important property of fresh concrete is its workability or flow ability, because this determines the ease with which it can be placed. It is determined using a slump test, in which a standard truncated metal cone form is filled with fresh concrete (Fig. 2). The mold is then lifted vertically, and the resulting loss in height of the concrete cone, or the slump value, is indicative of the concrete's workability. For very liquid mixes, the flow test is performed, which is similar to the slump test, except that the mean diameter of the cake formed by the fresh concrete (or mortar) is measured.

A short while after casting, the concrete stiffens and loses its plasticity. The time of setting can be determined by repeatedly dropping a calibrated needle into the fresh concrete and measuring the time when the needle no longer sinks in.

Figure 2: Concrete slump test with a slump of 1.5 in., typical for pavement work. (Portland Cement Association) [1]

PROPERTIES OF HARDENED CONCRETE

By far, the most important property of hardened concrete is its compressive strength. Since this strength continues to increase with continuing cement hydration, it is a function of age which is the time after casting. In the United States, the strength is determined 28 days after casting by loading standardized test cylinders up to failure. In Europe, test cubes are often used. Most commercially produced concrete has compressive strengths between 53.5739 and 107.1478 kg/mm.2 (20 and 40 MPa). If loaded in tension, the material fails at a stress much lower than that, typically of the order of 10% of the compressive strength. Because of this low (and unreliable) tensile strength, concrete is usually reinforced with steel bars.

During hydration and especially if allowed to dry after hardening, the concrete volume decreases by a small amount because of shrinkage. If this shrinkage is restrained somehow, it can lead to cracking. Shrinkage deformations caused by drying can be reversed only partially upon wetting. A concrete member or structure subjected to external load will undergo deformations which, up to a point, are proportional to the amount of applied load. If these loads remain in place for an appreciable time (months or years), these deformations will increase due to a material property called creep. Even for regular concrete mixes, creep deformations can be two or three times as high as the initial elastic deformations, especially if the concrete is loaded at a very young age. When designing concrete structures, such creep and shrinkage deformations must be accounted for.

Durability

Durability is the ability of a material (or structure) to maintain its various properties throughout its design or service life. Some concrete structures built by the Romans served for over 2000 years. A material that loses its strength in time, for whatever reason, cannot be considered durable.

There can be numerous causes for loss of durability or deterioration of concrete structures. The most common one is an excessive amount of cracking or pore structure. Most concrete structures contain numerous cracks. But as long as these remain small (of the order of 0.25 mm or less), they are generally invisible to the naked eye, and the concrete remains basically impermeable to salts and other aggressive agents, so that it can continue to protect the reinforcing steel against corrosion. Larger cracks provide easy access for such agents to the steel, thereby promoting corrosion. Since the steel corrosion products occupy a larger volume than sound steel, they produce internal pressure during expansion and can spall off the protective concrete cover, the loss of which may render the structure unsafe to resist loads [4].

The concrete itself may deteriorate or weather, especially if subjected to many cycles of freezing and thawing, during which the pressure created by the freezing water progressively increases the extent of internal cracking. In addition, carbon in the atmosphere can react chemically with the cement hydration products. This process is known as carbonation. It lowers the pH of the concrete matrix to the point where it can no longer protect the steel against corrosion.

Most types of aggregate used for concrete production are inert; that is, they do not react chemically with the cement or hydration products. However, there are various aggregate types, including those containing amorphous silica such as common glass, which react chemically with the alkali in the cement. In the presence of moisture, the alkali–aggregate reaction products can swell and cause considerable damage. The deterioration of numerous major structures and highway pavements has been attributed to such reactions, especially alkali–silica reaction, often after years of seemingly satisfactory service. Other common causes of chemical attack are sulfates found in soils, chlorides in seawater, acid rain, and other industrial pollutants. Generally, structures built with well-designed concrete mixes, having low porosity or high density and minimal cracking, are likely to resist most causes of chemical attack, although for service in particularly aggressive environments special countermeasures may have to be taken.

Under repeated load applications, structures can experience fatigue failure, as each successive load cycle increases the degree of cracking and material deterioration to the point where the material itself may gradually lose its strength or the increased extent of cracking is the source of loss of durability.

Thermal and other properties

The heavy weight of concrete [its specific gravity is typically 2.4 g/cm^3 (145 lb/ft^3)] is the source of large thermal mass. For this reason, massive concrete walls and roof and floor slabs are well suited for storing thermal energy. Because of this heat capacity of concrete, together with its reasonably low thermal conductivity, concrete structures can moderate extreme temperature cycles and increase the comfort of occupants. Well designed concrete mixes are impermeable to liquids and therefore suitable for storage tanks without the need for impermeable membranes or liners.

SPECIAL CONCRETES AND RECENT DEVELOPMENTS

Concrete is an engineered material, with a variety of specialty products designed for specific applications. Some important ones are described below.

Lightweight concrete

Although the heavy weight or large mass of typical concrete members is often an advantage, there are situations where this is not the case. For example, because of the large stresses caused by their own heavy weight, floor slabs are often made lighter by using special lightweight aggregate. To further reduce weight, special chemical admixtures are added, which produce large porosity. Such high porosity (in either the matrix or the aggregate particles themselves) improves the thermal resistance of the concrete as well as sound insulation, especially for higher frequencies. However, because weight density correlates strongly with strength, ultra light weight concretes [1.1 g/cm^3 (70 lb/ft^3) and less] are used only for thermal or sound insulation purposes and are unsuitable for structural applications [5].

Heavyweight concrete

When particularly high weight densities are needed, such as for shielding in nuclear reactor facilities, special heavyweight aggregate is used, including barite, limonite, magnetite, scrap metal, and steel shot for fine aggregate. Weight densities can be achieved that are twice that of normal weight concrete.

Architectural concrete

Concrete surfaces that remain exposed may call for special finishes or textures according to the architect's desires. Textures are most readily obtained by inserting special form liners before casting the concrete. Sometimes the negative imprint of roughly sawn timber is considered attractive and left without further treatment

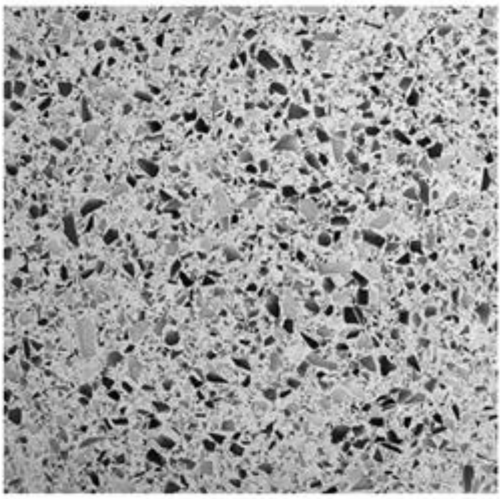

Figure 3: Glass concrete tile. (C. Meyer) [1]

Other surface textures are obtained by sandblasting, bush-hammering, and similar treatments. Ordinary portland cement gives concrete the typical gray color. By adding color pigments to the mix, a large variety of colors can be produced, especially in combination with white portland cement. Concrete mixed with specialty aggregate, such as marble, and ground smooth is known as terrazzo concrete, which is very popular for decorative surfaces on floors and walls. Recently, crushed postconsumer glass has been used as aggregate for decorative applications because of the esthetic possibilities, provided suitable counter measures against alkali–silica reaction are taken (Fig. 3).

Fiber-reinforced concrete

The concrete matrix can be reinforced with short, randomly distributed fibers. Fibers may be metallic (primarily steel), synthetic (such as polypropylene, nylon, polyethylene, polyvinyl alcohol, and alkali-resistant glass), or natural (such as sisal, coconut, and rice husk). Such fibers are typically used in addition to conventional steel reinforcement, but in some applications as its replacement. For example, precast glass-fiber reinforced building façade elements are widely used in the United States. By being uniformly distributed and randomly oriented, the fibers give the concrete matrix tensile strength, ductility, and energy absorption capacities that it otherwise would not have. In particular, when these fibers are engineered to optimize the fracture energy, so-called high-performance fiber-reinforced concrete is obtained, which has remarkable deformational characteristics and extraordinary resistance to blast and impact loads. In the concrete industry, it is very common to add small amounts of polypropylene fibers to reduce the extent of shrinkage cracking.

Textile-reinforced concrete

Whereas in fiber-reinforced concrete the fibers are short [usually no longer than 2 in. (5 cm)] and discontinuous, textile-reinforced concrete contains continuous woven or knitted mesh or textiles. Conceptually, such reinforcement acts similarly to conventional steel reinforcing bars or welded steel wire fabrics. But these fabric materials are noncorrosive and can have mechanical properties that are superior to those of steel. The fabrics can be pre manufactured in a wide variety of ways, thereby lending themselves to new applications, especially for repairing or strengthening existing concrete structures.

Polymer-modified concrete

In polymer-modified concrete, also known as latex-modified concrete, a polymer is added to improve the material's strength, imperviousness, or both. In applications such as highway bridge decks, often a layer of latex-modified concrete is placed on top of a regular reinforced concrete deck for additional protection of the steel reinforcement. In polymer concrete, the hydraulic cement is replaced by an organic polymer as the binder.

Roller-compacted concrete

This type of concrete is formulated with very low contents of portland cement and water and therefore is of relatively low-cost. It is often used for pavements and dams. It can be transported by dump trucks or loaders, spread with bulldozers or graders, and compacted with vibratory rollers. Because the cement content is so low, the heat of hydration does not cause the kind of problems encountered in dams built with conventional concrete.

Ultra-high-strength concrete

Whereas concretes with compressive strengths of 107.1478 to 214.29561 kg/mm.^{2} (40 to 85 MPa) can now be categorized as high-strength, a new technology has been developed that results in strengths of 535.73902 kg/mm.^{2} (200 MPa) and higher. The key ingredient of this ultra-high-strength concrete is a reactive powder; therefore, it is also known as reactive-powder concrete. Other characteristics of this material are low water–cement ratios, carefully selected high-strength aggregates, and small steel fibers.

Self-leveling concrete

The need for good workability has been mentioned. The need for highly skilled workers who can properly compact concrete at the construction site prompted researchers in Japan to optimize the mix design such that the fresh concrete can flow into place without the need for further vibration. The main challenge was to obtain a low viscosity mix without the threat of desegregation. This innovation is particularly important in applications with dense steel reinforcement, which traditionally have caused severe difficulties of producing high-quality concrete.

“Green” concrete

Concrete is by far the most widely used building material. Well over 10 billion tons are produced worldwide each year, requiring enormous natural resources. Also, it has been estimated that the production of 1 ton of portland cement causes the release of 1 ton of carbon dioxide (CO^2) into the atmosphere, a gas that is known to contribute to global warming. Together with the large amounts of energy required to produce portland cement, the cement and concrete industry has a major impact on the environment worldwide. Efforts are underway to reduce this impact and transform the industry to conform to the principles of sustainable development. The most significant step is the replacement of portland cement by other cementitious or pozzolanic materials, preferably materials that are byproducts of industrial processes, such as fly ash (the by-product of coal-burning power plants) and granulated blast furnace slag (a by-product of the steel industry). To reduce the need for virgin aggregate, recycled concrete is the most promising approach, because construction debris, in particular demolished concrete, constitutes a major component of solid waste that fills up sparse landfill capacity. These recent developments are much more advanced in Europe and Japan than in the United States. But the “green” building movement is gaining momentum there as well, and for the concrete industry to maintain its dominant position within the construction industry, it is undertaking major efforts to make concrete a more “green” material [6].

RECYCLED CONCRETE AGGREGATES

Concrete is globally the most widely used material in the construction industry. Basically, concrete is a manufactured product consisting of cement, aggregates, water and admixture. The composition of aggregates forms a major portion of the mixture consisting of sand, crushed stones and gravel which are inert granular materials. Construction aggregates make up more than 80 percent of the total aggregate market and are used mainly for building constructions and pavements. The word concrete comes from the Latin word ‘‘concretus’’ (meaning compact or condensed), the perfect passive participle of ‘‘concrescere’’, from the words ‘‘con’’ (together) and ‘‘crescere’’ (to grow). [7]

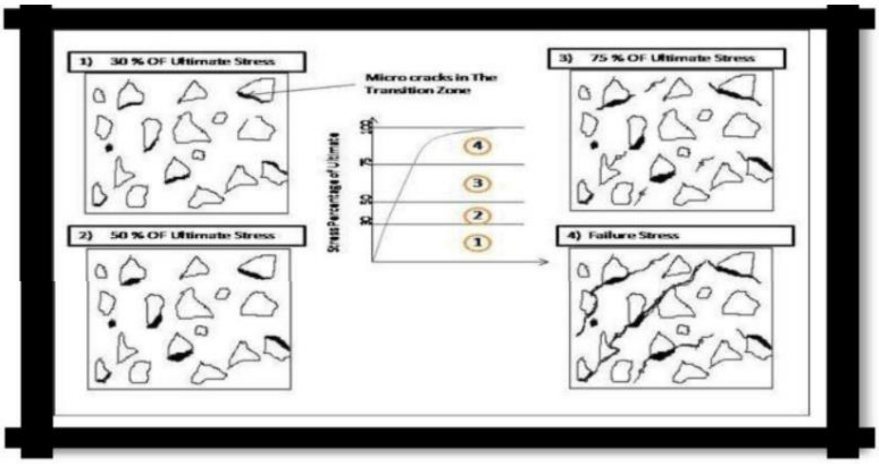

Figure 4: Stress-Strain Relationship of Ordinary Concrete [2]

Recycled aggregates are aggregates derived from the processing of materials previously used in construction. Examples include recycled concrete from construction and demolition waste material (C&D), reclaimed aggregate from asphalt pavement and scrap tyres. Coarse Recycled Concrete Aggregate (RCA) is produced by crushing sound, clean demolition waste of at least 95% by weight of concrete, and having a total contaminant level typically lower than 1% of the bulk mass. Other materials that may be present in RCA are gravel, crushed stone, hydraulic-cement concrete or a combination deemed suitable for pre-mix concrete production.

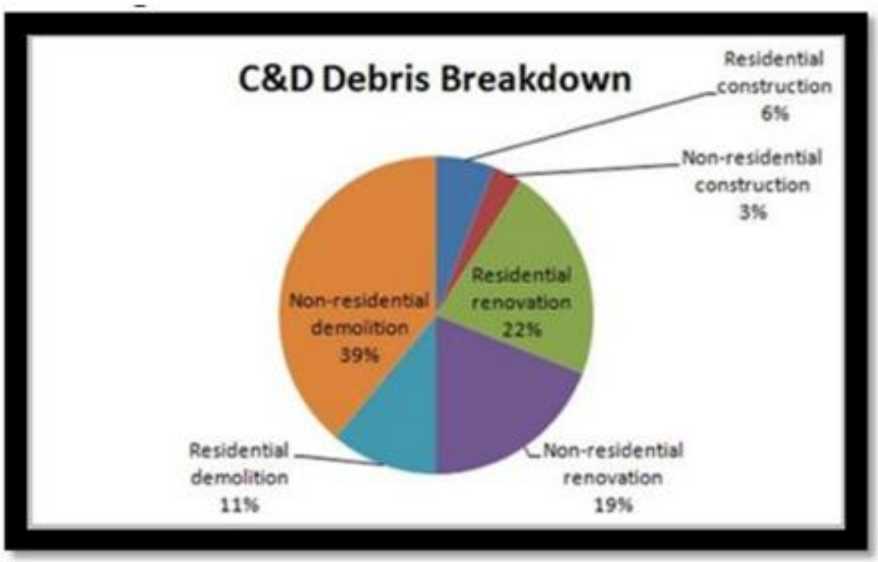

Figure 5: Worldwide Estimates of Construction and Demolition Waste [2]

CHAPTER - 2

LITERATURE REVIEW

Sowmya.et.al. (2000) [8], some tests were conducted using the recycled aggregates to study and compare the results with the naturally available aggregates. The tests were conducted on the aggregates which weren't subjected to any prior treatment. The impact value for recycled aggregate was obtained as 35% and that for natural aggregate as 29.9%. The abrasion value for recycled aggregate was obtained as 47.4% and that for natural aggregate as 29.6%. Water absorption of recycled aggregate (4.2%) was found to be higher when compared to the natural aggregate (0.4%). It was found that compressive strength of concrete made from the recycled aggregate is about 76%

of the strength of concrete made from natural aggregate for normal strength concrete (M20). Flexural strength of the recycled aggregate concrete is almost 85% and 80% of natural aggregate concrete.

Amnon.et.al (2002) [9], concrete having a 28-day compressive strength of 28 MPa was crushed at ages 1, 3 and 28 days to serve as a source of aggregate for new concrete, simulating the situation prevailing in precast concrete plants. The properties of the recycled aggregate and of the new concrete made from it, with nearly 100% of aggregate replacement, were tested. The properties of the concrete made with recycled aggregates were inferior to those of concrete made with virgin aggregates. Effects of crushing age were moderate: concrete made with aggregates crushed at age 3 days exhibited better properties than those made with aggregates of the other crushing ages.

Shailendra kumar.et.al. (2004) [10], in this paper, the author found the relationship between split tensile strength and compressive strength for RCA concrete as well as controlled concrete. The recycled concrete aggregate used was that passing through IS sieve 40 mm and retained on IS sieve 4.75 mm. For controlled concrete the natural stone chips of same nominal size was used in making concrete. If required a dose of super plasticizer [Conplast SP 430 (M)] was also added to ordinary tap water to obtain desired degree of workability. In this study, 3 mixes were prepared i.e. replacement of natural aggregates by 0%, 50% and 100% RCA. The strength was tested at 28 days maturity of casted concrete. It was observed that recycled concrete aggregate has lower value of specific gravity and moderately high values of water absorption, crushing value, impact value and abrasion value. Furthermore, similar to concrete containing natural aggregate, tensile strength of recycled aggregate concrete containing recycled concrete aggregate mainly depends on compressive strength.

Chaurpagar.et.al. (2004) [11], the author investigated physical and mechanical properties of RCA with and without steel fibres and polymer against controlled concrete. Specimens (cubes/beams/cylinders) were prepared by varying the parameters like water cement ratio and volume of polymer (2.5%, 5.0%, and 10% by parts weight of cement) and constant 0.5% steel fibre by volume of concrete. Recycled Aggregate and Natural Aggregate shows that the former has high specific gravity, high absorption capacity and low fineness modulus. Resistance to mechanical actions such as crushing strength, impact value and abrasion value of recycled aggregates are significantly higher than that of conventional aggregates. There is a marginal increase in the compressive strength due to the addition of polymer-steel fiber in recycled concrete. There is significant increase in split tensile strength and flexure strength at 90 days in polymer steel fiber recycled aggregate concrete as compared to conventional as well as recycled aggregate concrete. Area under stress strain curve is higher, shows the high toughness properties of concrete that it indicates that polymer concrete is more suitable for the earthquake resisting structures. It is observed that there is an improvement in the ductility with addition of 10% polymer & 0.5% steel fiber in the concrete as compared to recycled aggregate concrete as well as conventional concrete.

Limbachiya.et.al. (2004) [12], the report aimed at examining the performance of Portland Cement Concrete produced with natural and coarse aggregates. The study showed that because of attached cement paste in RCA, the density of these materials is about 3- 10% lower and water absorption is about 3-5 times higher than the corresponding natural aggregates. The results also indicate that for RCA samples obtained from four different sources, there was no significant variation in strength of concrete at a given RCA content.

Natesan.et.al. (2005) [13], an experimental investigation was conducted to study the mechanical properties of concrete where natural coarse aggregate is partially replaced with recycled coarse aggregate. It was concluded that RCA increases the mechanical properties of conventional concrete and it was observed that a mix of 75% RCA and 25% Natural Aggregates has good mechanical properties. RCA with rough surface allows better bonding with cement mix.

Naik.et.al. (2006) [14], this paper throws some light on the production of recycled aggregates, their properties and their suitability in the production of concrete. Also, the properties and the application of recycled aggregate concrete are discussed in detail along with bringing out the limitations of recycled aggregate concrete. This study showed that recycled aggregates had higher water absorption value than natural aggregates but less density and strength.

Choudary.et.al. (2006) [15], the author investigated workability and strength properties of RCA. The recycled aggregate concrete is made by mixing 60% of recycled aggregates with 40% of crushed stone chips. The aggregates used for concrete batching are maintained at saturated surface dry condition. The workability of the recycled aggregate concrete is slightly lower than that of the conventional concrete. The compressive strength of the recycled aggregate concrete is slightly lower than that of the conventional concrete and recycled concrete aggregate or recycled with conventional concrete can be used in normal plain and reinforced concrete construction. The recycled and conventional concrete containing 60% of recycled aggregate and 40% of crushed natural stone chips occupies almost an intermediate position is terms of workability and strength consideration between the others types of concrete. So from economy and performance point of view, this type of concrete is suitable only next to conventional concrete.

Osei.et.al. (2013) [16], in this study, the compressive strength properties of concrete were investigated by completely replacing Natural Aggregate (NA) with recycled concrete aggregate (RCA). Densities of both RCA concrete and NA concrete were within the range of normal weight concrete. Both RCA concrete and NA concrete showed the similar trends in the variation of strength and density with time. Reduction in the 28-day compressive strength of concrete due to complete replacement of natural aggregates with recycled concrete aggregate ranges from 11% to 33%. RCA can replace NA in the production of both non-structural and structural concrete.

Patil.et.al. (2013) [17], this study aimed to evaluate physical properties of concrete using recycled coarse aggregate. In this research, concrete waste from demolished structure has been collected and coarse aggregate of different percentages is used for preparing fresh concrete (0%, 25%, 50%, 75% & 100%). The compressive strength of recycled coarse aggregate (RCA) is found to be higher than the compressive strength of normal concrete when used up to a certain percentage. Recycled aggregate concrete is in close proximity to normal concrete in terms of split tensile strength. The slump of recycled aggregate concrete is more than the normal concrete. At the end, it can be said that the RCA up to 50 % can be used for obtaining good quality concrete.

PROPERTIES OF RECYCLED AGGREGATE

The use of recycled aggregate obtained from the waste concrete, as a component of the new concrete mixture, implies a thorough understanding of its basic properties, considering that some of them may significantly differ from the properties of aggregates obtained from natural resources. In addition, their differences primarily depend on the quantity and quality of cement mortar, which is attached to the grains of recycled aggregate (Figure 6), then, on the quality of the original concrete from which the aggregate is made by recycling and also on recycling methods. Nonetheless, in cases where the recycled aggregate comes from many different sources, the uneven quality, i.e. variations in the properties of recycled aggregate are much more pronounced than as is the case with natural aggregates.

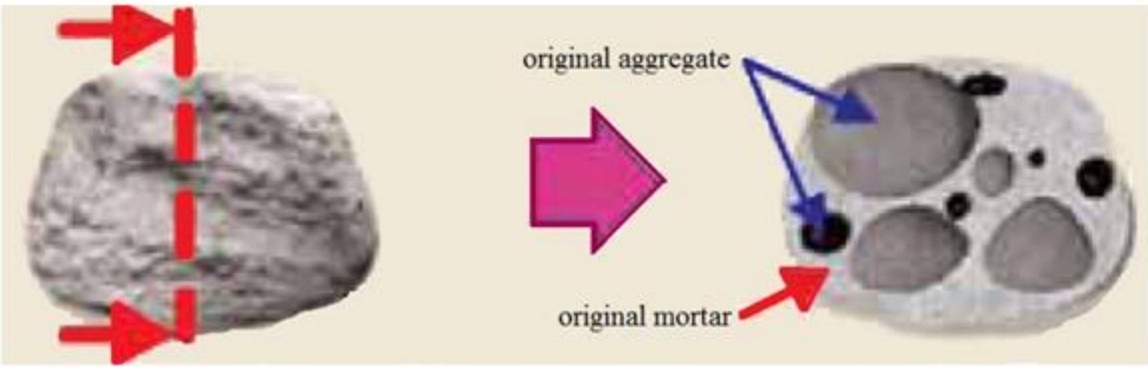

Figure 6: Appearance of the recycled aggregate grains [12]

Aggregate grading

Grading of recycled coarse aggregate normally satisfies the standards for natural aggregate, while in the case of recycled fine aggregate, composition corrections are often necessary, because, according to many practical experiences, it was found that there was often a certain amount of grains larger than what is required by standards for natural aggregate [18,19].

It has been shown that the presence of recycled fine aggregate has a negative impact on the physical-mechanical properties of concrete, therefore, even though through a careful mix design and application of appropriate production technology these effects can be reduced to an acceptable level, in practical application, a fine fraction of recycled aggregate is usually left out, in a way that it is completely replaced by the river sand [20, 21].

Shape and surface texture of aggregate particles

In terms of morphological characteristics, recycled aggregate is less favorable than natural aggregate. The grains are irregular, mostly with angular shape, rough and with cracked surface and porous. These grain characteristics grains significantly affect the workability of fresh concrete, as well as the permeability of liquids and gases in the hardened state; they also significantly depend on the properties of concrete used in recycling for production of aggregate, especially its strength, porosity, exploitation conditions to which it was subjected, but also on the ways and levels of recycling – the type of applied crusher and possible additional processing procedures.

Water absorption

Water absorption of recycled aggregate is a characteristic by which this aggregate differs most from the aggregate obtained from natural resources. According to all available research in this area, it has been shown that recycled concrete aggregate has a significantly higher absorption level compared to natural aggregates. The reason for that is that the original cement mortar, which is an integral part of the recycled aggregate, has a significantly more porous structure in comparison to natural aggregate, whereby its porosity primarily depends on the water cement ratio of the original (old) concrete. Thus, the absorption of water of recycled aggregate is even bigger, as the quantity of mortar, which is attached grains of the original recycled aggregate, increases. It has been shown in practice that the stated amount of cement mortar in recycled aggregate ranges from 25% to 65% (in volume percentage), and that it differs in certain fractions – the smaller the fraction, the greater the amount of cement mortar, as well as the level of water absorption [19]. Also, the analyses undertaken in extensive research around the world indicate that the stated amount of old cement mortar depends on the crushing method in the recycling process, thereby, according to some researchers, the maximum amount of mortar layer in recycled aggregate is recommended to less than 44% for constructional concrete. Additionally, the researchers from the University of Hong Kong recommend that the amount of recycled aggregate in structural concrete should range from 20% to 30%, in order to ensure that the maximum water absorption of aggregate used is less than 5% [22].

It is known that the aggregates from domestic natural resources have negligible absorption, up to 1% as maximum, while the value of the classically recycled coarse aggregate typically ranges within the interval from 3.5% to 10%, and for the fine aggregate, within the interval from 5.5% to 13% [19, 23]. According to the Japanese standard for the use of recycled aggregate as a component of concrete, there is a limit so that a coarse fraction of recycled aggregate whose absorption is not higher than

7%, and fine fractions whose absorption goes up to 13% [24], i.e. 10% can be used for the production of concrete.

Accordingly, the absorption capacity of recycled aggregates should be treated as one of the basic properties, which is to be taken into account while designing the mixture of new concrete on the basis of this aggregate. Through the influence on the water-cement ratio porosity and consistency, increased water absorption of recycled aggregate also influences a range of physical-mechanical properties of fresh, as well as hardened new concrete.

Bulk density of aggregate

The bulk density of the recycled aggregate, due to a higher porosity of mortar layer, has a lower value than the bulk density of natural aggregates and their mutual difference decreases if recycling is conducted by an advanced technology, which can remove a significant portion of the old cement mortar. Also, the smaller the fraction, the greater the amount of cement mortar in the total mass of aggregates, so the bulk density is accordingly lower. According to practical experience, it was shown that the bulk density of recycled aggregate was on the average by 10% lower compared to the bulk density of natural aggregates [22, 25, and 26].

Crushing and abrasion resistance

Mechanical properties of recycled aggregate are primarily dependent on the quality of the original cement mortar present in the aggregate, and also, as in the case with natural aggregates, depend on a number of other factors - the type of the original aggregate, structure, shape and size of grains, aggregate grading and so on.

The resistance to crushing and abrasion of recycled aggregate is less than the respective resistance of natural aggregate, which is a consequence of easier separation and crushing of the mortar layer around the recycled aggregate grains. In addition, recycled aggregate, in most cases, meets standard requirements in terms of the resistance to crushing and abrasion, which are prescribed for aggregates from natural resources. Their differences may widely range - from 0% up to 70%, which, as already pointed out, primarily depends on the quality, original concrete compressive strength, as well as the methods of crushing of recycled aggregate [19, 25]

Presence of harmful substances

Harmful substances, which may be present in recycled aggregate, are a consequence of harmful substances present in the original concrete, furthermore, of exposure of the original concrete to aggressive effects of various chemicals during the original exploitation, of inadequate levels of treatment during the recycling process, of possible mixing of different waste materials etc. These substances can be found in the following forms: lumps of clay, humus, gypsum, various organic substances (bitumen, wood, paper, cardboard, plastic, coal, plant materials, and various colors), steel and other metals, glass, lightweight concrete, brick, etc.

The presence of the stated components negatively affects the characteristics of the new concrete, and the studies show that they can cause a reduction in compressive strength by up to 15%.

According to the Japanese standard for use of recycled aggregate in concrete, the amount of harmful materials of density less than 1200 kg/m^3 is limited to 2 kg/m^3 , and plastic, clay, humus and other harmful substances of density less than 1950 kg/m^3 to 10 kg/m^3 .

In the event of contamination of recycled aggregate by gypsum, Rilem recommendations refer to the use of sulphate resisting cement, while the total content of sulphates should not be higher than 1% of the dry aggregate mass [24].

PROPERTIES OF FRESH RECYCLED AGGREGATE CONCRETE

Entrapped air content

The application of recycled coarse aggregate has no effect on the amount of entrapped air in fresh concrete, furthermore, the information about increase of the amount of entrapped air of up to 1% was found in some research - which can be considered as negligible.

Bulk density

An increase in a share of recycled aggregate in total mass of the component aggregate reduces the bulk density of fresh concrete, where it was shown that the bulk density of the recycled aggregate concrete was 5% to 10% lower than in the comparable natural aggregate concrete, while concretes made with the recycled coarse aggregate and natural fine aggregates had densities of 1% up to 5% lower than in the comparable natural aggregate concrete. In general, the values of bulk densities of the fresh concrete based on recycled aggregates range from 2280 kg/m^3 to 2360 kg m^3 [27-30].

Consistency

The use of recycled aggregate affects the consistency, in the sense that due to a usually higher absorption of recycled aggregate grains, as well as the less favorable grain shape and texture, the flow ability of the concrete mixture is reduced, while the specified property is also significantly affected by the method of preparation of recycled aggregate in the concrete mixing process. By using saturated, surface dry recycled aggregate, the consistency of the comparable concretes does not differ that much from the recycled and natural aggregates, while in the case of the use of dry recycled aggregate and extra amount of water, the same consistency can be achieved after the required time period [5 and 9].

PROPERTIES OF HARDENED CONCRETE

Rheological properties

Shrinkage of concrete increases as the share of recycled aggregate increases in the total weight of the component aggregate, considering that the recycled aggregate, due to the presence of the old mortar in its composition, has a lower elasticity modulus value, and therefore provides a lower resistance to shrinkage. According to available research it is shown that, in comparison to natural aggregate concrete, shrinkage values are 4% up to 70% higher when using recycled aggregate. In addition, in relation to the coarse fraction of the recycled aggregate, fine fraction influences more an increase in shrinkage. Also, the stated feature, as well as in the case of natural aggregate concrete, significantly depends on: air temperature and humidity, the quantity and type of applied cement, quantities of water and water cement ratio, aggregate grading, the size of the samples to be tested, etc.

The content of recycled aggregate significantly affects the creep deformations of concrete, in the sense that they increase alongside with an increase in the share of recycled aggregates - given that the creep deformation is proportional to the amount of cement mortar in concrete, which is more present in recycled aggregate concrete than in the comparable natural aggregate concrete. Based on a significant number of personally conducted experimental tests, it was shown that the creep of concrete, designed with a 100% content of the recycled aggregate in coarse fraction is by 25% to 60% larger than the creep of the comparable natural aggregate concrete and in the case of concrete in which the total quantity of aggregate is - recycled aggregate, the value of creep can be several times higher than in the case of comparable natural aggregates concrete. Therefore, in accordance with the creep characteristics, for the production of structural recycled aggregate concrete it is recommended that the recycled fine aggregate be replaced by natural sand, that is, that recycled coarse aggregate in the corresponding ratio be used, depending on its quality, structural requirements and environmental conditions.

Hydro-physical properties

Recycled aggregate concrete typically has higher absorption than comparable natural aggregate concrete, in the sense that an increase in share of recycled aggregate in total mass of the component aggregate proportionally increases the concrete absorption.

Water permeability of recycled aggregate concrete depends on the capillary porosity of the cement matrix of new concrete and capillary porosity of the cement matrix of recycled aggregate concrete. If the recycled aggregate is obtained by crushing small porosity concrete, permeability level of new concrete will primarily depend on the choice of aggregate grading and achieved structure of the new cement matrix, consequently, it is possible to produce water proof concrete by using recycled aggregate.

Physical-mechanical properties

Compressive strength of recycled aggregate concrete primarily depends on the quality of applied aggregates, so that it is possible to obtain higher, identical or lower strength compared to the natural aggregate concrete. In fact, a considerable amount of research confirms that in the case of application of recycled aggregate produced by concrete crushing, whose compressive strength was higher than the targeted compressive strength of new concrete, recycled aggregate concrete of equal or greater strength in relation to comparable natural aggregate concrete are obtained. Moreover, in case that the compressive strength values of the original concrete, of which recycled aggregate is manufactured, and targeted compressive strength value of new aggregate, were approximately equal, it was found that the strength values of recycled aggregate concrete was 5% to 10% lower than those of the comparable natural aggregate concrete. In case of designing such recycled aggregate concrete the targeted strength value is greater than the one of the original concrete (which is usually the case in practical application), lower strength class of recycled aggregate concrete is inevitably obtained than in the comparable natural aggregate concrete, while a decrease of strength depends on the level of application of such recycled aggregate. Furthermore, it was observed that during the application of both - fine and coarse recycled aggregate, the above mentioned decline in the strength of recycled aggregate concrete of 15% to 50%, compared to the comparable concrete made entirely with natural aggregate, occurs. The application of solely recycled coarse aggregate and natural sand leads to the maximum decrease of strength of such concrete in relation to the comparable one, in range of5% to 10%, while in the case of application of recycled aggregate in the amount up to 30% of coarse fractions (or up to 50% - differences in research) obtained concretes in which the decline of strength is generally negligible, if the strength of original concrete is not drastically lower than the target value of new concrete. Compressive strength values of concretes with a mixture of aggregates made of natural coarse aggregate and recycled fine aggregate is up to 50% lower in relation to the comparable natural aggregate concrete - which implies the exclusion of this combination in practical application. In addition to the above, the variations of compressive strength of recycled aggregate concrete depend on uniformity of quality of recycled aggregate, so potential problems in the practical application could occur if concretes without proper classification, i.e. with significant differences in compressive strength, is delivered to recycling plants.

An increase in the compressive strength during the period up to 28 days of age is usually higher in natural aggregate concrete in relation to concrete made entirely from the recycled aggregate, in ages higher than 28 days the situation is reversed, which is explained by the reaction of cement from previously unhydrated cement paste, attached from grains of recycled aggregates.

Tensile strength, usually determined by splitting tensile test through the line pressure, and more rarely by flexural tensile test, does not significantly depend on the type and amount of applied recycled aggregate (especially if only recycled coarse aggregate is used in the mixture), but, its primary function is the ratio of aggregates and cement amounts – an increase in this ratio reduces tensile strength. In fact, studies have shown that the presence of only coarse fraction of recycled aggregates causes a decrease in tensile strength upto the maximum 10%, whereby the level of participation of coarse fractions of recycled aggregate of 20% to 50% usually results in about 2% lower tensile strength in comparison to the concretes made entirely with natural aggregate. Differences in tensile strength in relation to natural aggregate concrete are to be expected in the range of 10% to 20% only in cases when concrete is prepared entirely with recycled aggregate. Thus, in relation to the coarse fraction, fine fraction of recycled aggregate has a slightly higher impact on this feature.

The tensile and compressive strength ratio in recycled aggregate concrete is lower than the ratio defined for natural aggregate concrete according to Eurocode 2 - which can be concluded by analysis of the diagram shown in Figure 7, where the test results of several researchers are summed up. In this regard, it is noted that the values in the diagram refer to different percentages of replacement of both - coarse and fine natural aggregate with the recycled one.

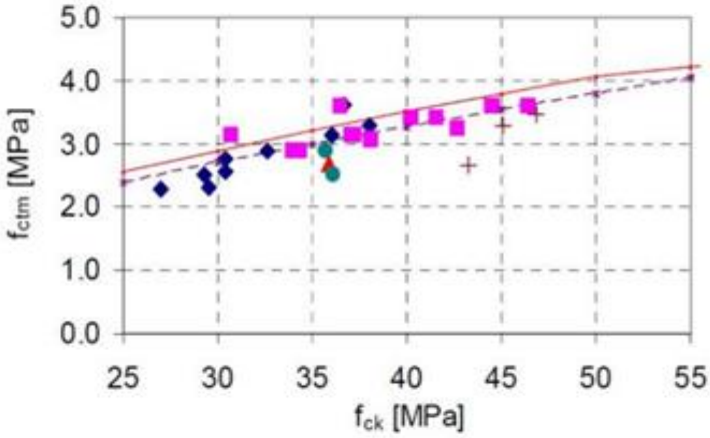

Figure 7: Diagram of relationship between tensile strength and compressive strength of recycled aggregate concrete [15]

The full line in the diagram shown in Figure 7 represents the connection between tensile and compressive strength according to Eurocode 2, i.e. according to equations 1 and 2 for the class up to C50/60, that is for the class higher than C50/60, respectively:

$f_{ctm} = 0{,}30. f_{ck}^{2/3}$ [MPa] (1) [15]

$f_{ctm} = 2{,}12. \ln(1 + \frac{f_{cm}}{10})$ [MPa] (2) [15]

Where:

f_{ctm} [MPa] – The mean value of axial tensile strength of concrete cylinder,

f_{ck} [MPa] – Characteristic compressive cylinder strength of concrete at 28 days and

f_{cm}[MPa] – The mean value of concrete cylinder compressive strength.

The dashed line in the diagram in Figure 4 represents a good approximation of the connection between tensile and compressive strengths, as already noted, by various experimental researches, which is derived by the modification of the above stated expressions in the form:

f_{ctm} = 0, 28. $f_{ck}^{2/3}$ [MPa] (3)
[15]

Based on the above, it can be seen that tensile and compressive strength ratio of recycled aggregate concrete is averagely by 7% lower than the ratio idefined for natural aggregate concrete according to Eurocode 2, regardless of the share of recycled aggregate in the total mass of applied aggregate.

The elasticity modulus of recycled aggregate concrete is lower than the one of comparable natural aggregate concrete, which is a consequence of significant amount of old cement mortar (in grains of recycled aggregates), which has relatively low elasticity modulus. Research suggests that the level of decrease of modulus significantly depends on the type of fine fraction in the aggregate mass. In fact, in concrete with 100% content of recycled coarse aggregate and natural fine aggregate, a decline of elasticity modulus in relation to concrete made entirely with natural aggregate goes up to 20%, while in the case of concrete produced entirely of recycled aggregates, decline of elasticity modulus ranges from 15% to 45% in relation to natural aggregate concrete. Also, it is interesting to note that several studies have noted that the difference level in elasticity modulus between recycled aggregate concrete and natural aggregate concrete depends also on the compressive strengths of observed concretes, in the sense that for concretes with middle values of strength of up to 30 MPa the difference in the modulus values is almost negligible, while on the other hand, with the increase in strength above the stated value, the difference between the subjected modules increases.

<u>Abrasion resistance</u>

The use of recycled aggregate concrete influences abrasion resistance, in a way that an increase in the quantity of this aggregate reduces resistance to abrasion, due to higher amount of cement matrix, which is more easily abraded than the grains of natural aggregates.

Adhesion between concrete and reinforcement does not significantly depend on the presence of recycled aggregate in the mixture, since the adhesion is achieved through the new cement matrix.

Exploitation properties in sense of durability

General conclusions about the characteristics essential for the durability of concrete with recycled aggregate cannot be made due to contradictory conclusions in the existing literature. However, the facts related to the existence of two interfacial transition zones and usually higher permeability of concrete based on recycled aggregate in relation to the comparable natural aggregate based concrete; indicate greater vulnerability to degrading mechanisms during exploitation. However, as permeability largely depends on the size, distribution and continuity of capillary pores in cement matrix and interfacial transition zones in concrete structure, by applying the above-described specificities related to the composition, design and preparation of these types of concrete, it is possible to produce satisfactory, even high performance concretes, in terms of durability [20, 25, 31−41].

NEED FOR RECYCLED AGGREGATE

Urbanization growth rate in India is very high due to industrialization. Growth rate of India is reaching 9% of GDP. Rapid infrastructure development requires a large quantity of construction materials, land requirements & the site. For large construction, concrete is preferred as it has longer life, low maintenance cost & better performance. For achieving GDP rate, smaller structures are demolished & new towers are constructed. Protection of environment is a basic factor which is directly connected with the survival of the human race. Parameters like environmental consciousness, protection of natural resources, sustainable development, play an important role in modern requirements of construction works. Due to modernization, demolished materials are dumped on land & not used for any purpose. Such situations affect the fertility of land. As per report of Hindu online of March 2007, India generates 23.75 million tons demolition waste annually. As per report of Central Pollution Control Board (CPCB) Delhi, in India, 48 million tons solid waste is produced out of which 14.5 million ton waste is produced from the construction waste sector, out of which only 3% waste is used for embankment.

Out of the total construction demolition waste, 40% is of concrete, 30% ceramic's, 5% plastics, 10% wood, 5%metal, & 10% other mixtures. As reported by global insight, growth in global construction sector predicts an increase in construction spending of 4800 billion US dollars in 2013. These figures indicate a tremendous growth in the construction sector, almost 1.5 times in 5 Years.

For production of concrete, 70-75% aggregates arerequired. Out of this 60-67% is of coarse aggregate & 33-40% is of fine aggregate. As per recent research by the Fredonia group, it is forecast that the global demand for construction aggregates may exceed 26 billion tons by 2012. Leading this demand is the maximum user China 25%, Europe 12% & USA 10%, India is also in top 10 users. From environmental point of view, for production of natural aggregates of 1 ton, emissions of 0.0046 million ton of carbon exist where as for 1 ton recycled aggregate produced only 0.0024 million ton carbon is produced. Considering the global consumption of 10 billion tons/year of aggregate for concrete production, the carbon footprint can be determined for the natural aggregate as well as for the recycled aggregate.

The use of recycled aggregate generally increases the drying shrinkage creep & porosity to water & decreases the compression strength of concrete compared to that of natural aggregate concrete. It isnearly 10-30% as per replacement of aggregate.

Recycling reduces the cost (LCC) by about 34-41% & CO_2 emission ($LCCO_2$) by about 23-28% for dumping at public / private disposal facilities.

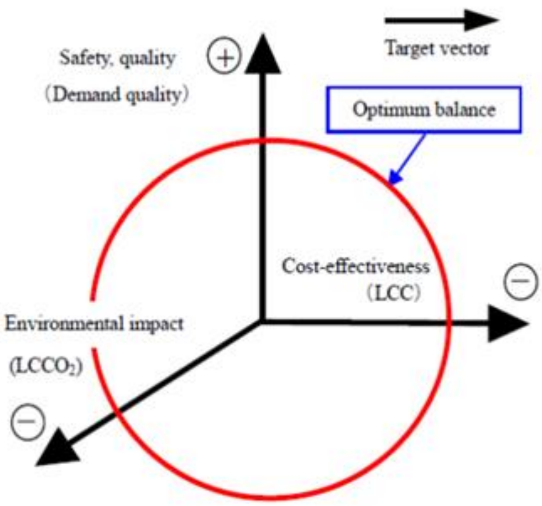

Figure 8: Evaluation of recycling [15]

Advantages of recycling of construction materials

- Used for construction of precast & cast in situ gutters & kerb's.
- Cost saving: - There are no detrimental effects on concrete & it is expected that the increase in the cost of cement could be offset by the lower cost of Recycled Concrete Aggregate (RCA).
- 20% cement replaced by fly ash is found to control alkali silica reaction (ASR).
- Save environment: - There is no excavation of natural resources & less transportation. Also less land is required.
- Save time: - There is no waiting for material availability.
- Less emission of carbon due to less crushing.
- Up to 20% replacement of natural aggregate with RCA or recycled mixed aggregates (RMA) without a need for additional testing for all concrete up to a characteristic strength of 65 MPa, as per Dutch standard VBT 1995, is permitted.

Limitations or disadvantages of recycling of construction material

- Less quality (e.g. compressive strength reduces by 10-30%).
- Duration of procurement of materials may affect life cycle of project.
- Land, special equipments machineries are required (more cost).

- Very high water absorption (up to 6%).
- It has higher drying shrinkage & creep.

CHAPTER - 3

EXPERIMENTAL METHODOLOGY

ARTIFICIAL NEURAL NETWORK

The compressive strength of concrete is a major and important mechanical property, which is generally obtained by measuring concrete specimens after a standard curing of 28 days. Conventional methods of predicting 28-day compressive strength of concrete are basically based upon statistical analysis by which many linear and nonlinear regression equations have been constructed to model such a prediction problem (Hakim, 2006) [42].

Obviously, obtaining test values of the early strength concrete takes time and results in a delay of time in forecasting the 28-day strength. Furthermore, choosing a suitable regression equation involves technique and experience and is not a simple task. Such traditional prediction models have been developed with a fixed equation form based on a limited number of data and parameters. If the new data is quite different from the original data, then the model should update to include its coefficients and also its equation form.

Artificial Neural Networks (ANNs) do not need such a specific equation form. Instead of that, it needs sufficient input-output data. Also, it can continuously re-train the new data, so that it can conveniently adapt to the new data. ANN has been investigated to deal with problems involving incomplete or imprecise information (Noorzaei et al., 2007) [43].

Several authors have used ANNs in structural engineering. For example, Yeh (1998) [44], Kasperkiewicz et al. (1995) [45], Lai and Sera (1997) [46] and Lee (2003) [47] applied the NN for predicting properties of conventional concreteand high performance concretes.

Bai et al. (2003) [48] developed neural network models that provide effective predictive capability with respect to the workability of concrete incorporating metakaolin (MK) and fly ash (FA). Guang and Zong (2000) [49] proposed a method to predict 28-day compressive strength of concrete by using multilayer feed forward neural networks. Dias and Pooliyadda (2001) [50] used back propagation neural networks to predict the strength and slump of ready mixed concrete and high strength concrete, in which chemical admixtures and mineral additives were used.

ANN are data processing systems consisting of a large number of simple, highly interconnected processing elements (artificial neurons) in an architecture inspired by the structure of the central cortex of the brain. They have the ability to learn from experience in order to improve their performance and to adapt themselves to changes in the environment (Hola and Schabowicz, 2005 [51]; Mansour et al., 2004) [52].

ANNs can provide meaningful answers even when the data to be processed include errors or are incomplete and can process information extremely rapidly when applied to solve real world problems.

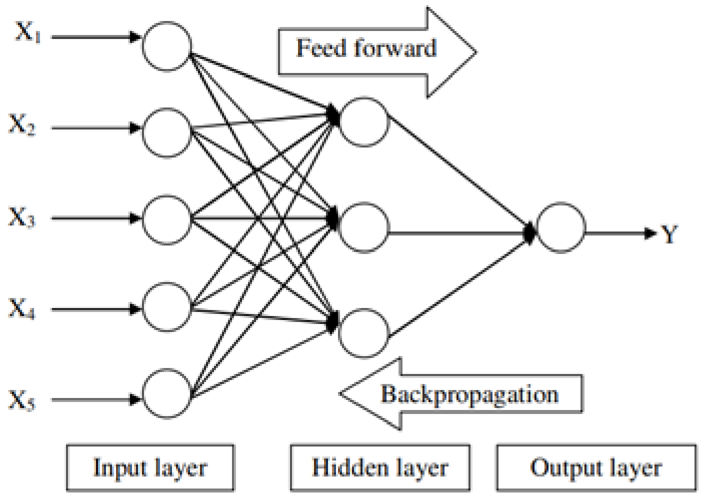

Figure 9: Architecture of a typical multilayer feed forward neural network [50]

As shown in Figure 9, a typical neural network has three layers: The input layer, the hidden layer and the output layer. The MFNN model is one of the most commonly used ANN models, whose application stretches to almost every field. Each neuron in the input layer represents the value of one independent variable. The neurons in the hidden layer are only for computation purpose. Each of the output neurons computes one dependent variable. Signals are received at the input layer, pass through the hidden layer, and reach the output layer.

Table 1: Data base with 177 mixes selected from 15 studies on the effect of incorporating RCA.

Nº	C	FA	W	SP	FNA	CNA	RCA	FM	WA	SSD	TM	F_c	Ref.

								of FNA					
	kg	Kg	Kg	%	kg	kg	Kg		%	g/cm^3	Mm	MPa	
1	500	0	150	0.1	725	1087	0	2.11	1.1	2.62	10	77.2	[53]
2	400	100	150	0.16	707	1087	0	2.11	1.1	2.62	10	75.04	[53]
3	637	0	150	2.89	711	936	0	2.16	1.1	2.62	10	77.92	[54]
4	475	158	150	2.89	681	924	0	2.16	1.1	2.62	10	84.72	[54]
5	347	283	148	3.76	639	920	0	2.16	1.1	2.62	10	71.52	[54]
6	702	0	135	5	641	949	0	2.16	1.1	2.62	10	77.44	[54]
7	512	173	133	5.07	620	932	0	2.16	1.1	2.62	10	81.84	[54]
8	372	305	130	4.99	608	927	0	2.16	1.1	2.62	10	70.8	[54]
9	390	0	195	0	768	917	0	2.11	1.1	2.62	20	28.64	[55]
10	312	78	195	0	615	1143	0	2.11	1.1	2.62	20	31.44	[55]
11	500	0	150	0.5	758	927	0	2.11	1.1	2.62	20	68.72	[56]
12	400	100	150	0.8	618	1147	0	2.11	1.1	2.62	20	66.16	[56]
13	350	150	150	0.7	615	1143	0	2.11	1.1	2.62	20	64.16	[56]
14	300	200	150	0.7	613	1139	0	2.11	1.1	2.62	20	61.36	[56]
15	390	0	195	0	768	917	0	2.11	1.1	2.62	20	28.64	[56]
16	273	117	195	0	626	1133	0	2.11	1.1	2.62	20	31.44	[56]
17	234	156	195	0	625	1129	0	2.11	1.1	2.62	20	29.52	[56]
18	350	115	175	1.6	785	735	0	2.64	0.85	2.63	20	38.8	[57]
19	270	145	160	2.23	870	750	0	2.64	0.85	2.63	20	51.6	[57]
20	500	0	150	1.5	724	1086	0	2.16	1.1	2.62	10	69.44	[58]
21	425	75	150	1.5	700	1086	0	2.16	1.1	2.62	10	68.8	[58]
22	375	125	150	1.85	683	1086	0	2.16	1.1	2.62	10	68.32	[58]
23	275	225	150	2.1	650	1086	0	2.16	1.1	2.62	10	57.44	[58]
24	225	275	150	2.6	634	1086	0	2.16	1.1	2.62	10	45.92	[58]
25	400	0	150	1	710	1157	0	2.16	1.1	2.62	20	48.56	[58]
26	340	60	160	1.1	690	1157	0	2.16	1.1	2.62	20	44.8	[58]
27	300	100	160	1.2	660	1157	0	2.16	1.1	2.62	20	39.44	[58]
28	220	180	160	1.3	634	1157	0	2.16	1.1	2.62	20	35.12	[58]
29	180	220	160	1.6	621	1157	0	2.16	1.1	2.62	20	29.84	[58]
30	410	0	205	0	609	1132	0	2.16	1.1	2.62	20	40.64	[58]
31	348.5	61.5	205	0	589	1132	0	2.16	1.1	2.62	20	39.12	[58]
32	307.5	102.5	205	0	576	1132	0	2.16	1.1	2.62	20	33.36	[58]
33	225.5	184.5	205	0	549	1132	0	2.16	1.1	2.62	20	28.48	[58]
34	184.5	225.5	205	0	536	1132	0	2.16	1.1	2.62	20	19.2	[58]
35	500	0	150	1.5	724	1086	0	2.16	1.1	2.62	10	66	[58]
36	425	75	150	1.5	700	1086	0	2.16	1.1	2.62	10	62.32	[58]
37	375	125	150	1.85	683	1086	0	2.16	1.1	2.62	10	63.28	[58]
38	375	225	150	2.1	650	1086	0	2.16	1.1	2.62	10	51.2	[58]
39	225	275	150	2.6	634	1086	0	2.16	1.1	2.62	10	45.68	[58]
40	400	0	160	1	710	1157	0	2.16	1.1	2.62	20	44.64	[58]
41	340	60	160	1.1	690	1157	0	2.16	1.1	2.62	20	35.84	[58]
42	300	100	160	1.2	660	1157	0	2.16	1.1	2.62	20	35.28	[58]
43	220	180	160	1.3	634	1157	0	2.16	1.1	2.62	20	26.16	[58]
44	180	220	160	1.6	621	1157	0	2.16	1.1	2.62	20	25.92	[58]
45	410	0	205	0	609	1132	0	2.16	1.1	2.62	20	34.08	[58]

46	348.5	61.5	205	0	589	1132	0	2.16	1.1	2.62	20	30.48	[58]
47	307.5	102.5	205	0	576	1132	0	2.16	1.1	2.62	20	28.16	[58]
48	225.5	184.5	205	0	549	1132	0	2.16	1.1	2.62	20	24.32	[58]
49	184.5	225.5	205	0	536	1132	0	2.16	1.1	2.62	20	20.72	[58]
50	410	0	225	0	642	1048	0	2.11	1.1	2.62	20	38.88	[59]
51	410	0	225	0	642	840	204	2.11	1.62	2.61	20	36.24	[59]
52	410	0	225	0	642	524	506	2.11	2.41	2.58	20	34	[59]
53	410	0	225	0	642	210	814	2.11	3.22	2.56	20	31.36	[59]
54	410	0	225	0	642	0	1017	2.11	3.77	2.54	20	29.68	[59]
55	307.5	102.5	225	0	628	1048	0	2.11	1.1	2.62	20	37.68	[59]
56	307.5	102.5	225	0	628	840	204	2.11	1.62	2.61	20	35.04	[59]
57	307.5	102.5	225	0	628	524	506	2.11	2.41	2.58	20	34.24	[59]
58	307.5	102.5	225	0	628	210	814	2.11	3.22	2.56	20	31.12	[59]
59	307.5	102.5	225	0	628	0	1017	2.11	3.77	2.54	20	29.36	[59]
60	410	0	225	0	642	0	1017	2.11	3.77	2.53	20	30.48	[60]
61	307.5	102.5	225	0	611	1048	0	2.11	1.11	2.62	20	34.88	[60]
62	307.5	102.5	225	0	611	840	204	2.11	1.64	2.6	20	34.24	[60]
63	307.5	102.5	225	0	611	524	506	2.11	2.44	2.58	20	33.36	[60]
64	307.5	102.5	225	0	611	0	1017	2.11	3.77	2.53	20	29.44	[60]
65	266.5	143.5	225	0	598	1048	0	2.11	1.11	2.62	20	32.56	[60]
66	267.5	143.6	225	0	598	840	204	2.11	1.64	2.6	20	32.8	[60]
67	268.5	143.7	225	0	598	524	506	2.11	2.44	2.58	20	29.68	[60]
68	269.5	143.8	225	0	598	0	1017	2.11	3.77	2.53	20	20.16	[60]
69	400	0	180	0	708	1108	0	2.11	1.11	2.62	20	53.44	[60]
70	400	0	180	0	708	886	215	2.11	1.64	2.6	20	49.92	[60]
71	400	0	180	0	708	554	538	2.11	2.44	2.58	20	45.44	[60]
72	400	0	180	0	708	0	1075	2.11	3.77	2.53	20	41.68	[60]
73	300	100	180	0	688	1108	0	2.11	1.11	2.62	20	43.52	[60]
74	300	100	180	0	688	886	215	2.11	1.64	2.6	20	39.76	[60]
75	300	100	180	0	688	554	538	2.11	2.44	2.58	20	35.44	[60]
76	300	100	180	0	688	0	1075	2.11	3.77	2.53	20	31.6	[60]
77	260	140	180	0	688	1108	0	2.11	1.11	2.62	20	36.72	[60]
78	260	140	180	0	688	886	215	2.11	1.64	2.6	20	34.88	[60]
79	260	140	180	0	688	554	538	2.11	2.44	2.58	20	32.32	[60]
80	260	140	180	0	688	0	1075	2.11	3.77	2.53	20	30.64	[60]
81	390	0	195	0	678	1107	0	2.11	1.12	2.62	20	46	[61]
82	390	0	195	0	678	527	539	2.11	2.56	2.57	20	42.24	[61]
83	390	0	195	0	678	0	1078	2.11	4.01	2.52	20	39.2	[61]
84	253.5	136.5	195	0	640	1107	0	2.11	1.12	2.62	20	34	[61]
85	253.5	136.5	195	0	640	527	539	2.11	2.56	2.57	20	34.8	[61]
86	253.5	136.5	195	0	640	0	1078	2.11	4.01	2.52	20	29.6	[61]
87	380	0	190	0	687	1120	0	2.11	0.74	2.64	20	44.8	[62]
88	380	0	190	0	687	0	1025	2.11	6.74	2.4	20	39.84	[62]
89	380	0	190	0	687	0	1039	2.11	3.03	2.44	20	40.32	[62]
90	380	0	190	0	687	0	1043	2.11	1.87	2.44	20	42.08	[62]
91	355	0	195	0	690	1127	0	2.11	1.11	2.62	20	35.04	[62]
92	355	0	195	0	690	902	205	2.11	1.6	2.6	20	33.52	[62]
93	355	0	195	0	690	564	543	2.11	2.41	2.57	20	30.56	[62]

94	355	0	195	0	690	0	1085	2.11	3.76	2.52	20	29.2	[62]
95	355	0	195	0	690	902	193	2.11	1.97	2.58	20	32.96	[62]
96	355	0	195	0	690	564	520	2.11	3.44	2.52	20	29.12	[62]
97	355	0	195	0	690	0	1038	2.11	5.96	2.42	20	27.44	[62]
98	355	0	195	0	690	902	199	2.11	2.04	2.6	20	33.28	[62]
99	355	0	195	0	690	564	534	2.11	3.6	2.55	20	30.24	[62]
100	355	0	195	0	690	0	1068	2.11	6.23	2.48	20	28.48	[62]
101	353	0	209	0	666	1093	0	2.11	1.24	2.62	20	36.8	[63]
102	353	0	206	0	661	864	216	2.11	2.34	2.57	20	34.4	[63]
103	353	0	207	0	649	531	531	2.11	3.98	2.49	20	30.48	[63]
104	353	0	209	0	625	0	1026	2.11	6.71	2.36	20	31.28	[63]
105	353	0	214	0	667	1086	0	2.11	1.24	2.62	20	38.64	[63]
106	353	0	221	0	667	1080	0	2.11	1.24	2.62	20	32.16	[63]
107	353	0	217	0	660	861	209	2.11	2.31	2.57	20	35.92	[63]
108	353	0	230	0	661	853	202	2.11	2.29	2.57	20	34.56	[63]
109	353	0	229	0	647	527	513	2.11	3.94	2.49	20	35.76	[63]
110	353	0	247	0	647	524	496	2.11	3.9	2.49	20	31.76	[63]
111	353	0	241	0	625	0	993	2.11	6.71	2.36	20	37.44	[63]
112	353	0	271	0	625	0	959	2.11	6.7	2.36	20	34.64	[63]
113	379	0	190	0	623	1237	0	2.1	1.24	2.62	20	33.2	[64]
114	379	0	190	0	590	0	1171	2.1	8.2	2.41	20	26.08	[64]
115	379	0	190	0	590	0	1171	2.1	6.61	2.39	20	30.96	[64]
116	420	105	184	0.7	668	1002	0	2.11	1.1	2.62	20	56	[65]
117	420	105	184	0.7	668	0	916	2.11	6.49	2.4	20	39.68	[65]
118	420	105	184	0.7	668	0	938	2.11	5.55	2.45	20	43.44	[65]
119	420	105	184	0.7	668	0	922	2.11	5.81	2.41	20	50.72	[65]
120	420	105	184	0.7	668	0	940	2.11	5.53	2.46	20	56	[65]
121	420	105	184	0.7	668	0	923	2.11	6.59	2.41	20	58.16	[65]
122	300	0	205	0	697	1143	0	2.19	1.01	2.6	20	27.6	[66]
123	300	0	205	0	697	0	1075	2.19	3.36	2.48	20	28	[66]
124	300	0	205	0	697	0	1027	2.19	6.14	2.36	20	23.36	[66]
125	300	0	205	0	697	0	1040	2.19	6.44	2.36	20	22.16	[66]
126	350	0	180	0	706	1158	0	2.19	1.01	2.6	20	38.64	[66]
127	350	0	180	0	706	0	1089	2.19	3.36	2.48	20	38.08	[66]
128	350	0	180	0	706	0	1041	2.19	6.14	2.36	20	33.6	[66]
129	350	0	180	0	706	0	1054	2.19	6.44	2.36	20	34.32	[66]
130	425	0	185	0	696	1092	0	2.19	1.01	2.6	20	49.28	[66]
131	425	0	185	0	696	0	1028	2.19	3.36	2.48	20	48	[66]
132	425	0	185	0	696	0	982	2.19	6.14	2.36	20	42.96	[66]
133	425	0	185	0	696	0	994	2.19	6.44	2.36	20	42.96	[66]
134	485	0	165	0	685	1094	0	2.19	1.01	2.6	20	64.4	[66]
135	485	0	165	0	685	0	1030	2.19	3.36	2.48	20	62.56	[66]
136	485	0	165	0	685	0	979	2.19	6.14	2.36	20	56.96	[66]
137	485	0	165	0	685	0	982	2.19	6.44	2.36	20	52.32	[66]
138	350	0	180	0	675	0	1089	2.19	6.14	2.36	20	39.36	[66]
139	350	0	180	0	654	0	1041	2.19	6.44	2.36	20	34.88	[66]
140	425	0	185	0	637	0	1028	2.19	6.14	2.36	20	48.32	[66]
141	425	0	185	0	618	0	982	2.19	6.44	2.36	20	45.84	[66]

142	440	0	155	0	666	1166	0	2.19	0.71	2.66	20	55.68	[66]
143	440	0	155	0	666	0	1070	2.19	6.38	2.41	20	47.52	[66]
144	440	0	155	0	666	0	1077	2.19	5.18	2.42	20	55.84	[66]
145	440	0	155	0	666	0	1083	2.19	5.36	2.44	20	54.24	[66]
146	440	0	155	0	666	0	1090	2.19	5.3	2.45	20	54.96	[66]
147	440	0	155	0	666	0	1094	2.19	5.36	2.46	20	49.68	[66]
148	380	0	190	0	710	1110	0	2.19	0.71	2.66	20	43.52	[66]
149	380	0	190	0	710	1055	44	2.19	1.27	2.63	20	43.52	[66]
150	380	0	190	0	710	999	88	2.19	1.85	2.61	20	43.92	[66]
151	380	0	190	0	710	944	132	2.19	2.44	2.58	20	42	[66]
152	380	0	190	0	710	1055	43	2.19	1.53	2.63	20	43.36	[66]
153	380	0	190	0	710	999	86	2.19	2.38	2.61	20	41.84	[66]
154	380	0	190	0	710	944	129	2.19	3.24	2.61	20	37.52	[66]
155	370	0	185	0	732	1090	0	2.19	1.01	2.6	20	38.56	[66]
156	370	0	185	0	732	545	463	2.19	2.31	2.55	20	40.24	[66]
157	370	0	185	0	732	0	924	2.19	3.85	2.49	20	39.36	[66]
158	425	0	192	0.19	730	963	0	2.58	1.4	2.61	25	35.52	[67]
159	428	0	193	0.18	734	969	0	2.58	1.4	2.61	25	34.24	[67]
160	429	0	193	0.22	736	729	230	2.58	2.24	2.58	25	30.16	[67]
161	423	0	190	0.18	726	479	453	2.58	3.1	2.54	25	31.44	[67]
162	427	0	192	0.28	733	242	687	2.58	3.99	2.51	25	28.24	[67]
163	426	0	192	0.35	731	0	913	2.58	4.9	2.47	25	30.08	[67]
164	431	0	195	0.1	741	489	457	2.58	3.33	2.53	25	28.08	[67]
165	433	0	195	0.27	744	0	918	2.58	5.4	2.44	25	29.04	[67]
166	427	0	192	0.19	734	484	451	2.58	3.28	2.52	25	26.88	[67]
167	432	0	194	0.23	742	0	912	2.58	5.3	2.43	25	27.52	[67]
168	430	0	193	0.2	737	0	917	2.58	4.7	2.46	25	25.28	[67]
169	429	0	193	0.22	737	0	909	2.58	5.1	2.44	25	27.28	[67]
170	316	0	194	0.11	803	953	0	2.58	1.4	2.61	25	23.44	[67]
171	320	0	192	0.13	819	0	914	2.58	4.9	2.47	25	21.68	[67]
172	322	0	193	0.09	823	0	908	2.58	5.4	2.44	25	19.92	[67]
173	320	0	192	0.1	819	0	899	2.58	5.3	2.43	25	16.4	[67]
174	645	0	194	0.36	563	973	0	2.58	1.4	2.61	25	46.8	[67]
175	645	0	193	0.46	563	0	921	2.58	4.9	2.47	25	36.4	[67]
176	642	0	192	0.51	561	0	905	2.58	5.4	2.44	25	45.68	[67]
177	642	0	192	0.44	561	0	902	2058	5.3	2.43	25	37.68	[67]

MODEL

For that IS code 10262-2019 has been used. The first trial of M40 mix design is taken:

Cement = 412 kg/m^3

Water = 148 kg/m^3

Fine aggregate (SSD) = 648 kg/m^3

Coarse aggregate (SSD) = 1234 kg/m^3

Chemical admixture = 4.12 kg/m^3

Free water-cement ratio = 0.36

The aggregates shall be used in saturated surface dry condition. If otherwise, when computing the requirement of mixing water, allowance shall be made for the free (surface) moisture contributed by the fine and coarse aggregates. On the other hand, if the aggregates are dry, the amount of mixing water shall be increased by an amount equal to the moisture likely to be absorbed by the aggregates. Necessary adjustments are also required to be made in mass of aggregates. The surface water and percentage water absorption of aggregates shall be determined according to IS 2386.

FINEST MODULUS

To calculate Finest Modulus of Fine Natural Aggregate (FM of FNA), sieve analysis have been carried out of 2 kg sand.

A sieve analysis (or gradation test) is a practice or procedure used in civil engineering and chemical engineering to assess the particle size distribution (also called gradation) of a granular material by allowing the material to pass through a series of sieves of progressively smaller mesh size and weighing the amount of material that is stopped by each sieve as a fraction of the whole mass.

The size distribution is often of critical importance to the way the material performs in use. A sieve analysis can be performed on any type of non-organic or organic granular materials including sand, crushed rock, clay, granite, feldspar, coal, soil, a wide range of manufactured powder, grain and seeds, down to a minimum size depending on the exact method. Being such a simple technique of particle sizing, it is probably the most common.

Figure 10: Sieve Analysis

Table 5: Sieve Analysis

Sieve	Weight retained (kg)	% weight retained	Cumulative weight retained	% passing
4.75 mm	0.015	0.75	0.5	99.8
2.36 mm	0.034	1.7	2.45	99.5
1.18 mm	0.642	32.1	34.55	65.45
600 µm	0.236	11.8	46.33	53.65
300 µm	0.796	39.8	86.15	13.83
150 µm	0.196	9.8	95.96	4.04

FM of FNA = 2.66

WATER ABSORPTION

Figure 11: Water absorbtion for SSD

Figure 12: Water absorption for SSD (III)

Figure 13: Oven

3 samples were oven dried for 5 hours, and then put into water for 24 hours. The surface was then cleaned with dry cloth, and the weighing was done.

Calculated water absorption is mentioned in the following table:

Table 6: Water Absorbtion

	NA	20% RCA	50% RCA
Water absorption	1.1	1.6	2.3
SSD (density)	2.63	2.6	2.58

The following stones were collected from a demolished site and crushed be a hammer until 20mm of the nominal size was obtained.

Figure 14: Demolished site

Figure 15: Stones Collected

Figure 16: Hammer

Figure 17: Crushed Stones

After that coarse aggregate was made for three samples. First three cubes has natural coarse aggregate of nominal size 20 mm. The second and third cube are made by replacing 20% and 50% of coarse aggregate with demolished waste of 20 mm nominal size respectively. Finally 9 cubes were formed using 1% superplastisizer/silka plast.

Three samples have been created for testing:

Table 2: Creation of 3 samples

	Sample 1	Sample 2	Sample 2
No. of cubes	3	3	3
	Natural Aggregate	20% replacement by demolished waste	50% replacement by demolished waste

Natural coarse aggregate have been formed. First three cubes have natural coarse aggregate of nominal size 20 mm.

Volume of cubes = 0.030375 m^3

For 3 cubes of Natural Aggregate, the following calculations have been done:

Cement = 4.5883 kg

Water = 1.782 kg

Fine Aggregate =7.15 kg

Coarse Aggregate = 13.677 kg

Chemical admixture = 0.0458 kg

Table 3: Creation of samples

	Natural Aggregate	20% replacement	50% replacement
Cement (kg/m^3)	4.5883	4.5883	4.5883
Water (kg/m^3)	1.782	1.782+0.5*	1.782+0.5*
Fine Aggregate (kg/m^3)	7.15	7.15	7.15
Coarse Aggregate (kg/m^3)	13.677	NCA = 10.9412 RCA = 2.7354	NCA = 6.8385 RCA =6.8385
Chemical admixture (kg/m^3)	0.0458		

* extra water has been added to maintain consistency

Figure 18: Formation of cubes

Figure 19: Formation of cubes (II)

Figure 20: N = all natural aggregate; R2 = replacement of 20%; R5 = replacement of 50%

These cubes are then placed for accelerated curing in Accelerated Curing Tank (ACT) as per the code guidelines. As per IS 9013 code, cubes have been kept for 24 hours. After 24 hours, the cubes have been put in ACT and tested.

Figure 21: Accelerated Curing Tank

For 24 hours, the cubes were casted, and then placed inside the curing tank for 3-4 hours. Then the cubes are placed for normal curing for around 2 hours.

Figure 22: Cubes under the process of curing

The cubes are then placed under the CTM

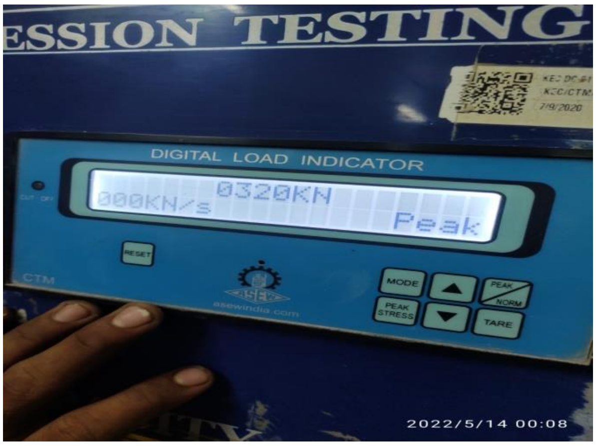

Figure 23: CTM Testing (I)

Figure 24: CTM testing for R2 cube (I)

Figure 25: CTM testing for R2 cube (II)

Figure 26: CTM testing (II)

Figure 27: CTM testing for R5 cube (I)

Figure 28: CTM testing (III)

Figure 29: CTM testing for R5 cube (II)

Table 4: compressive strength

NA	R2	R5
416 kN	320 kN	318 kN
355	329 kN	311 kN
381.4	318.455	247.36

$R_{28} = 8.09+1.64 \times R_a$

	st_{28} for NA (MPa)	st_{28} for R2 (MPa)	st_{28} for R5 (MPa)
Cube 1	38.41172	30.538	30.758
Cube 2	33.96	32.07008	31.26
Cube 3	35.89	31.3019	32.12
Average	36.088	31.3019	31.3793

CONCLUSION AND FUTURE SCOPE

Now the validation was done using MATLAB tool

<u>Dataset</u>

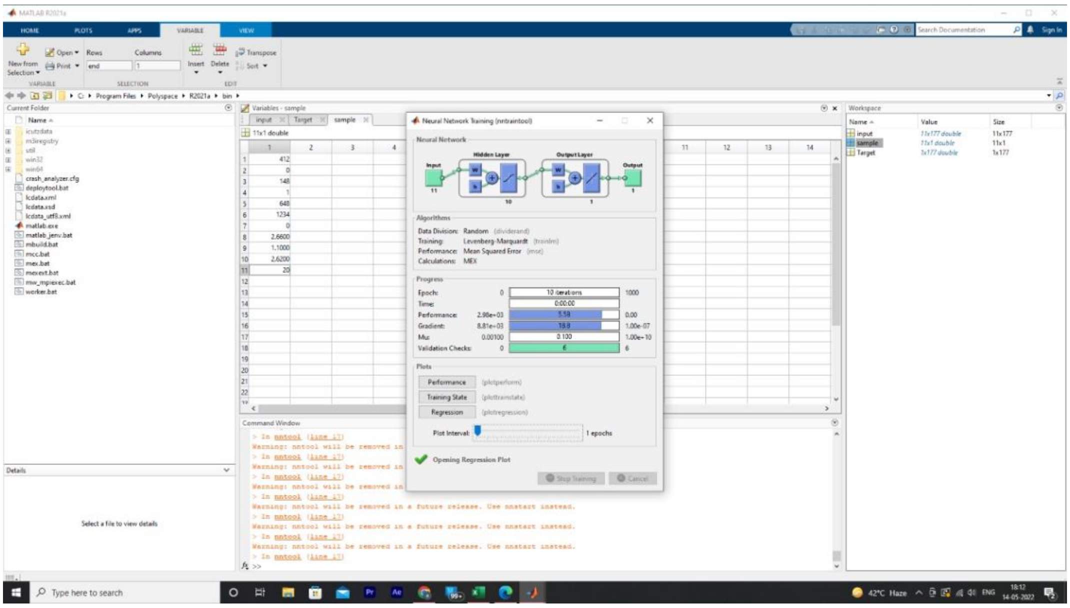

Figure 30: Result (I)

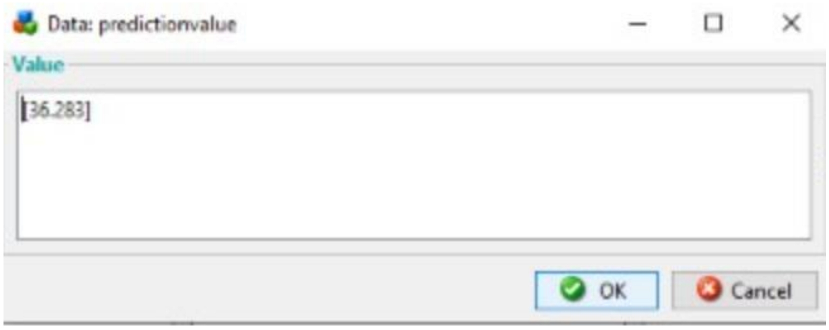

Figure 31: Result (II)

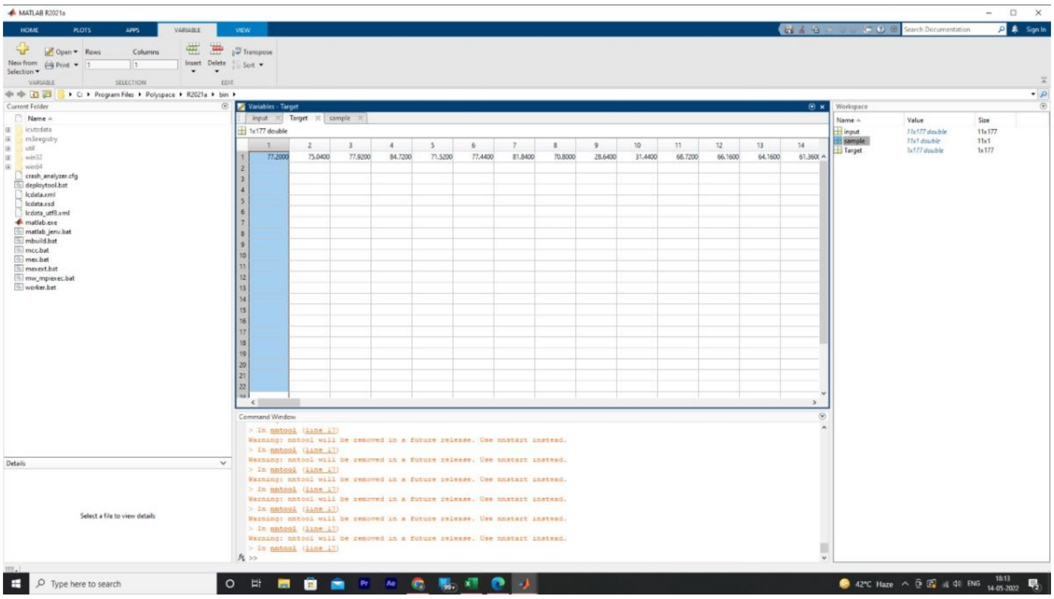

Figure 32: Result (III)

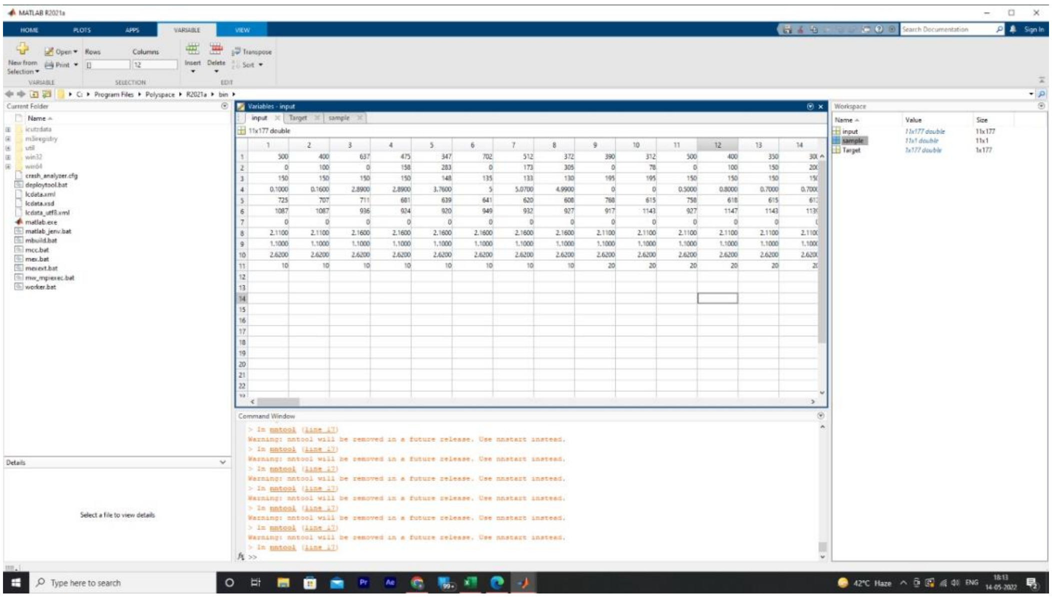

Figure 33: Result (IV)

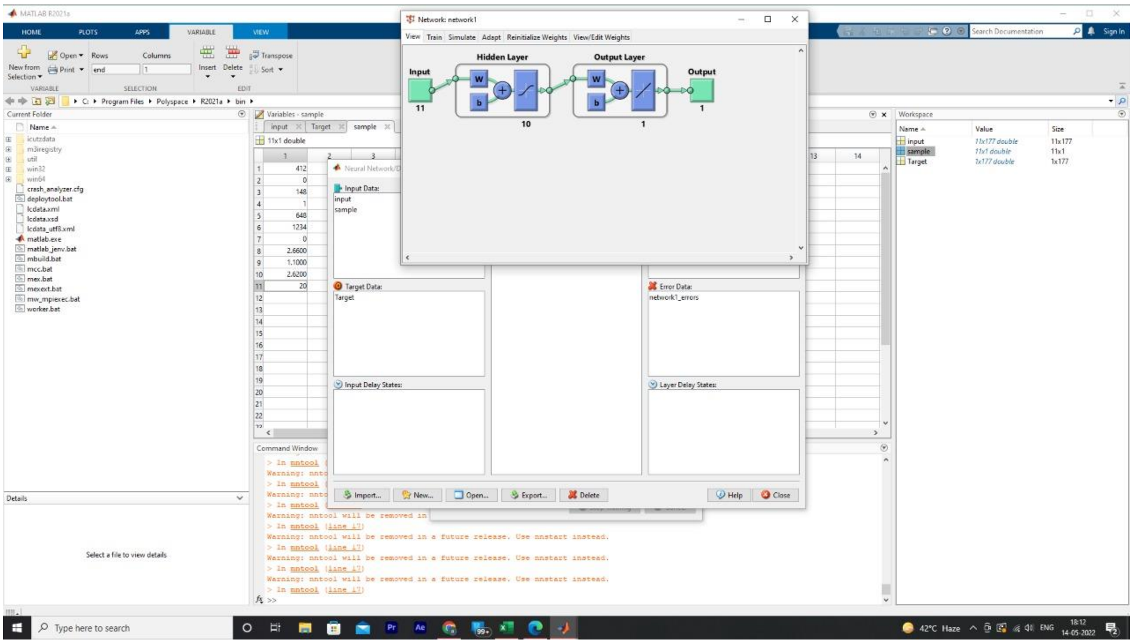

Figure 34: Result (V)

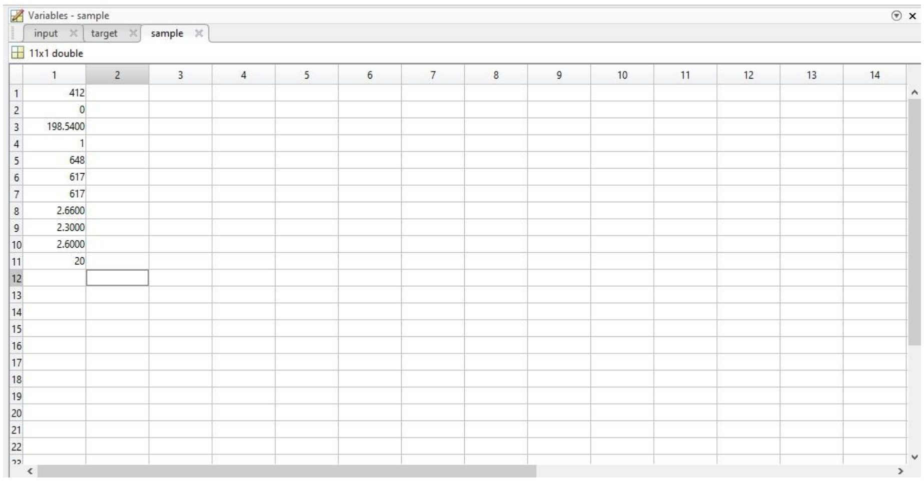

Figure 35: Result (VI)

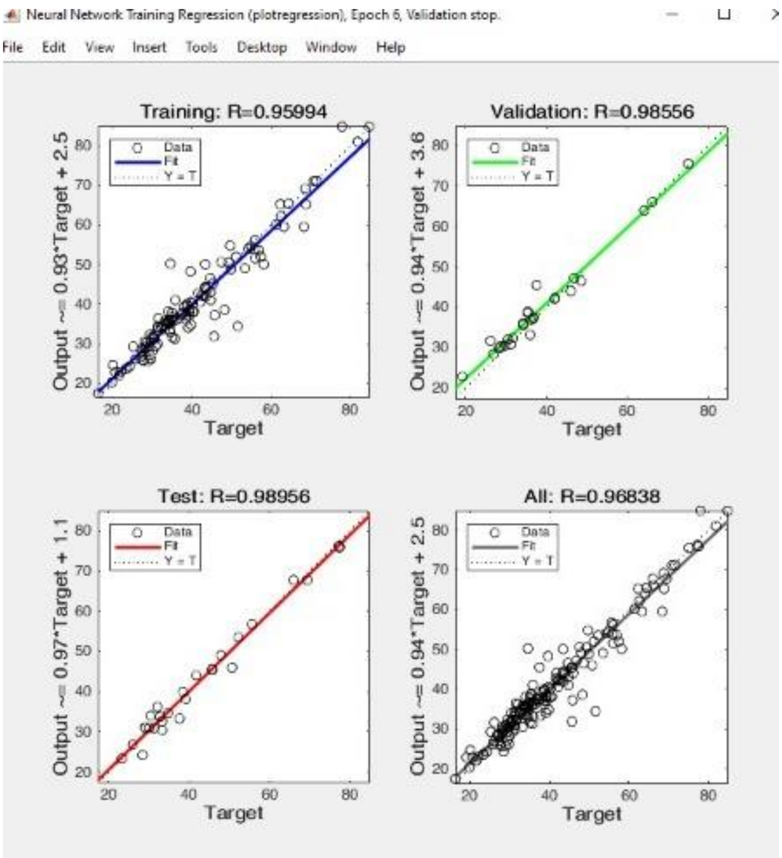

Figure 36: Result (VII)

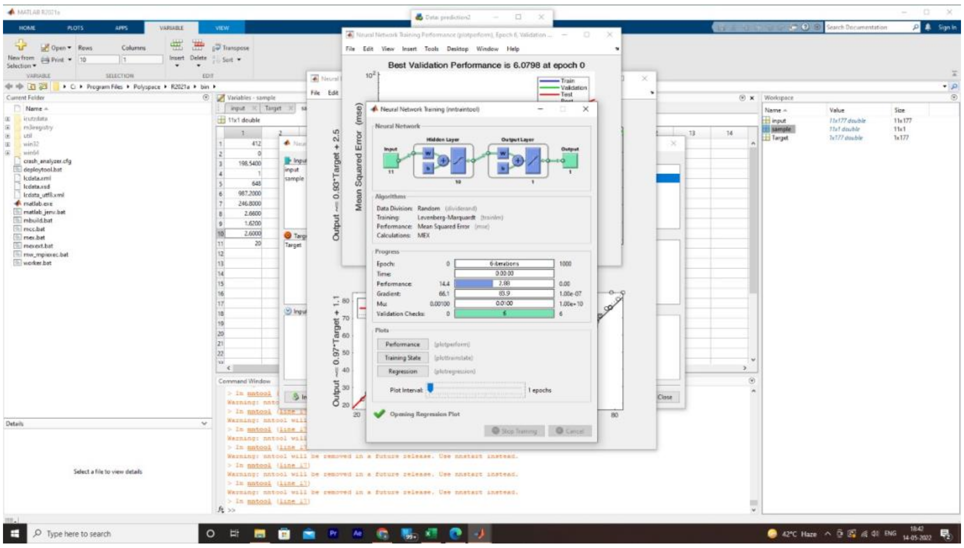

Figure 37: Result (VIII)

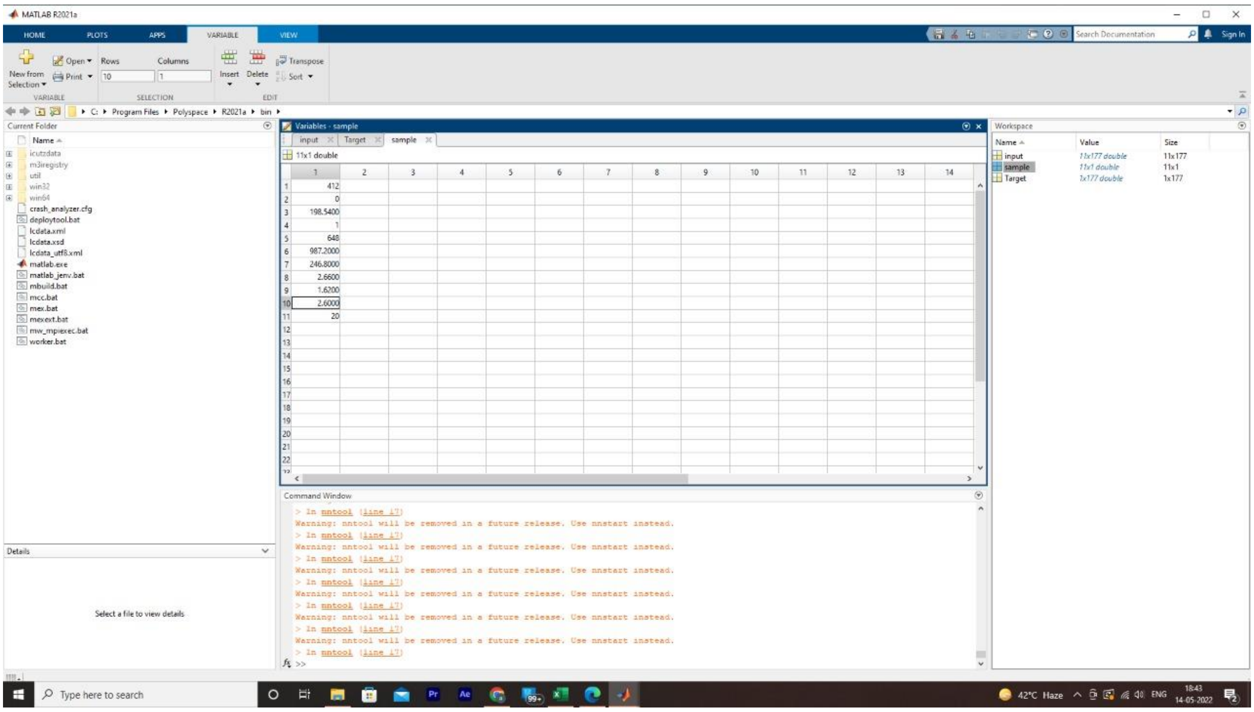

Figure 38: Result (IX)

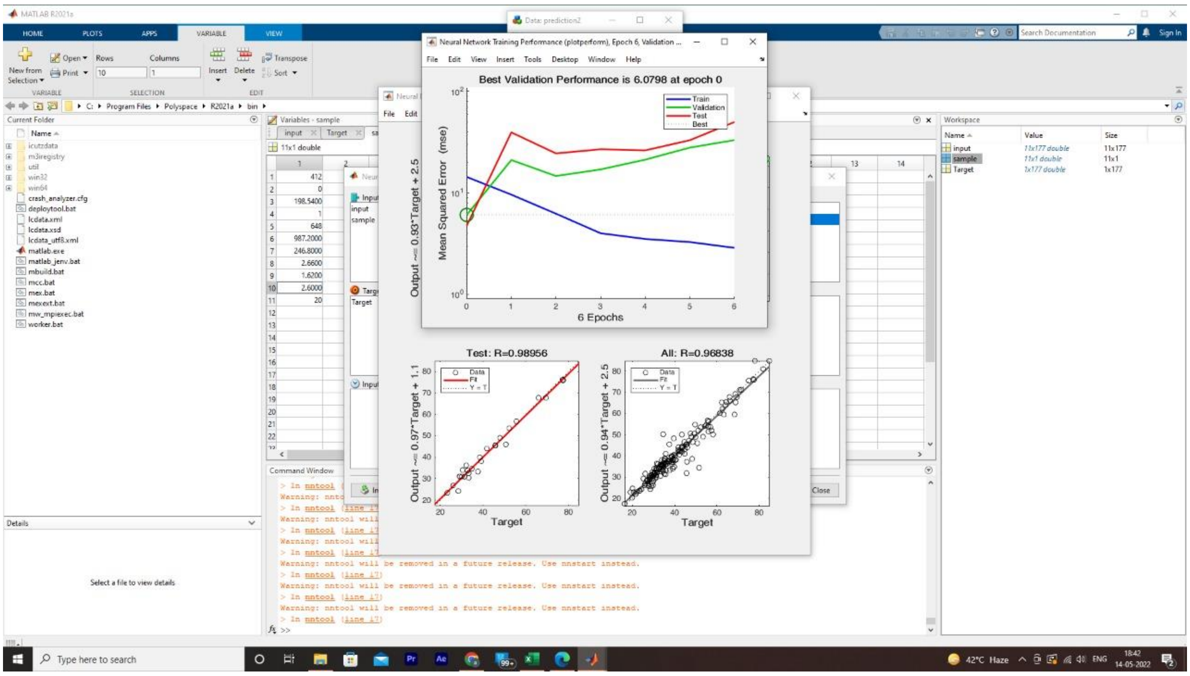

Figure 39: Result (X)

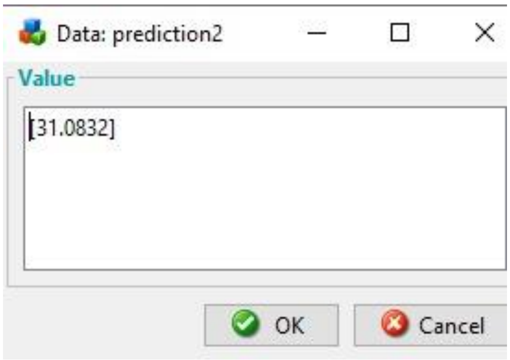

Figure 40: Result (XI)

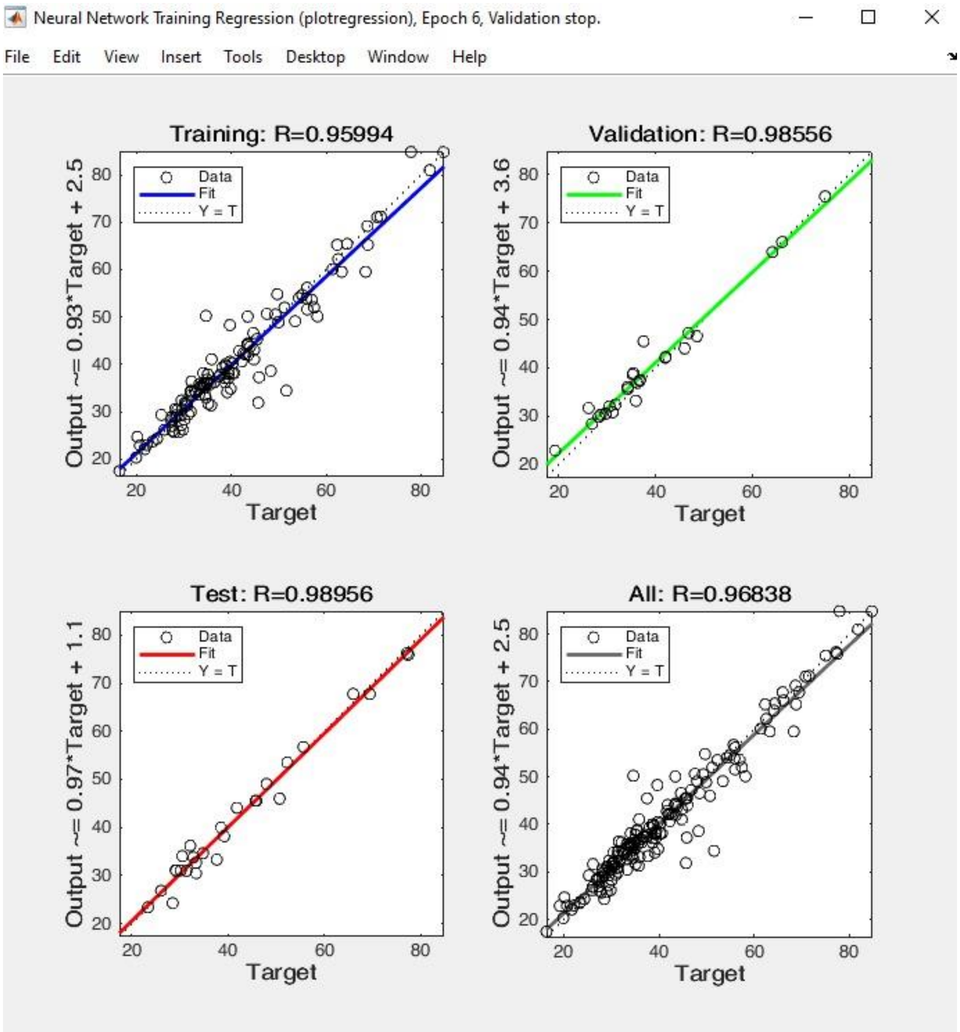

Figure 41: Result (XII)

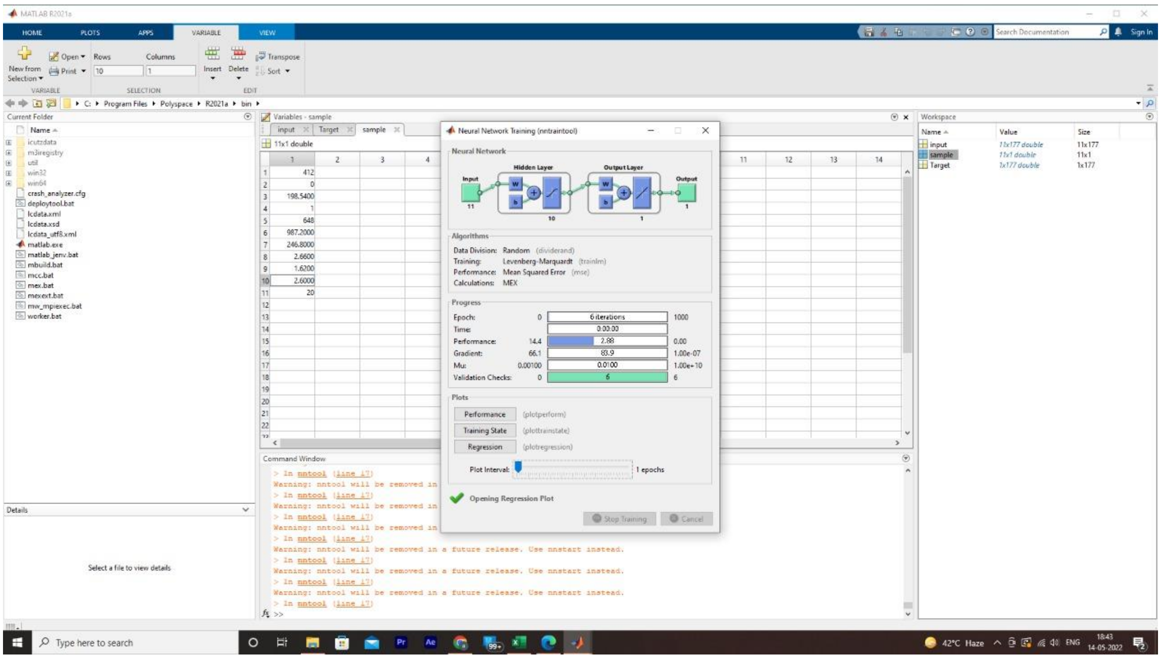

Figure 42: Result (XIII)

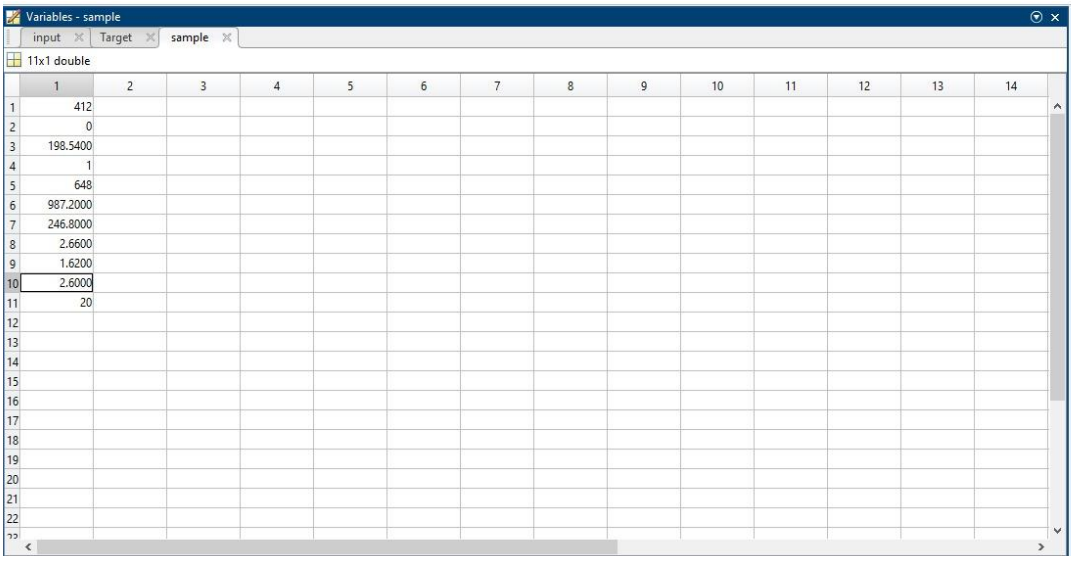

Figure 43: Result (XIV)

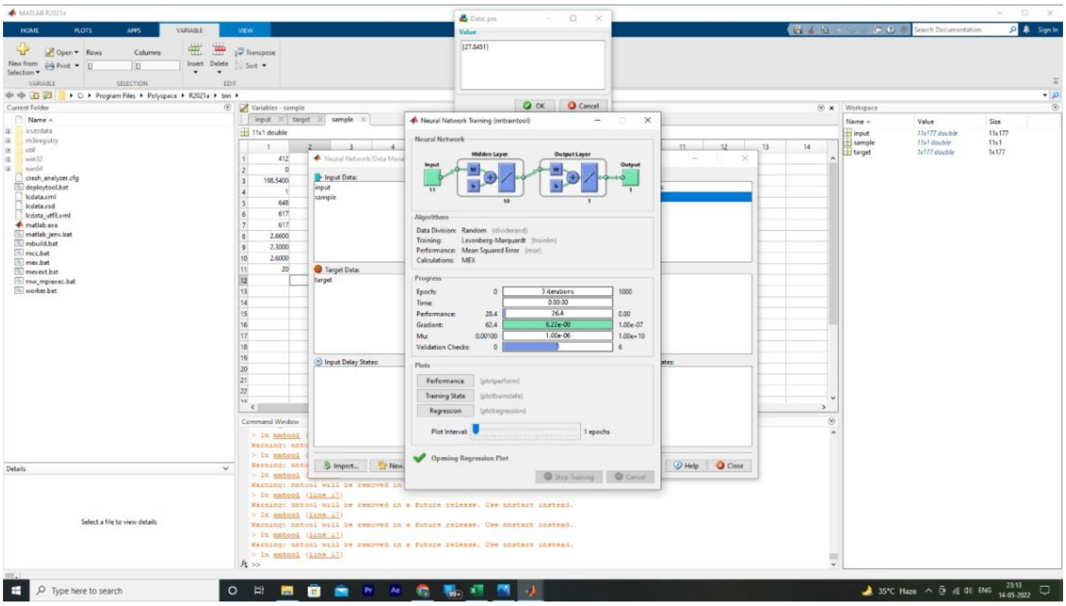

Figure 44: Result (XV)

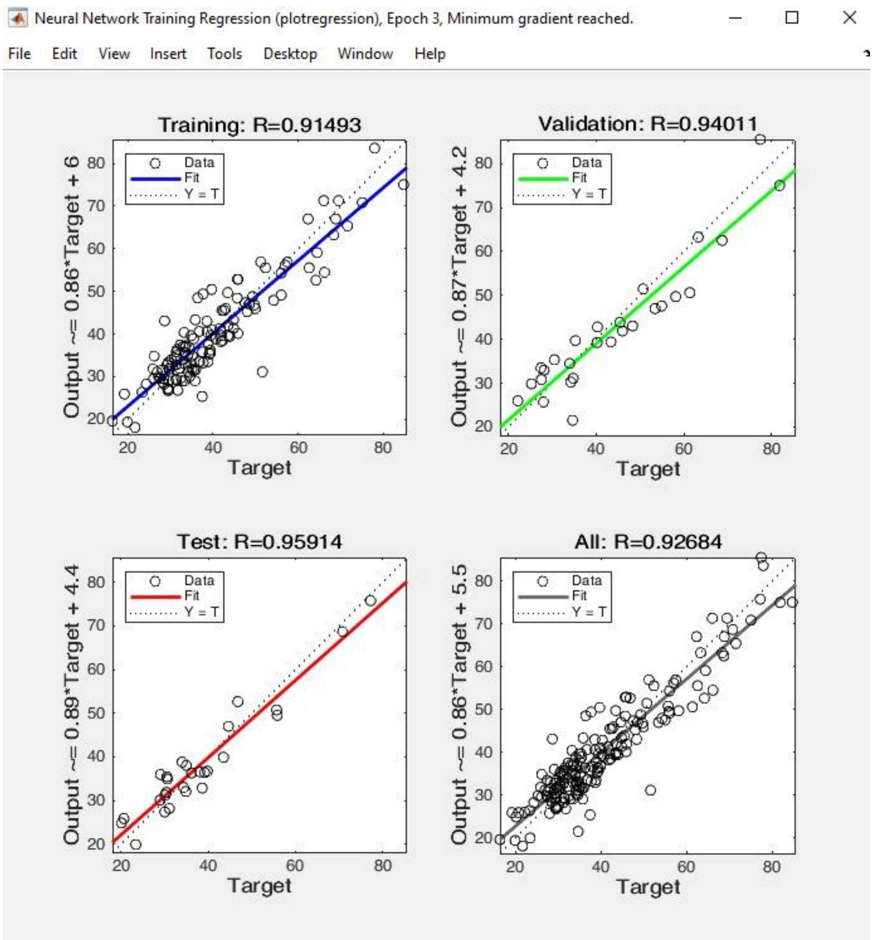

Figure 45: Result (XVI)

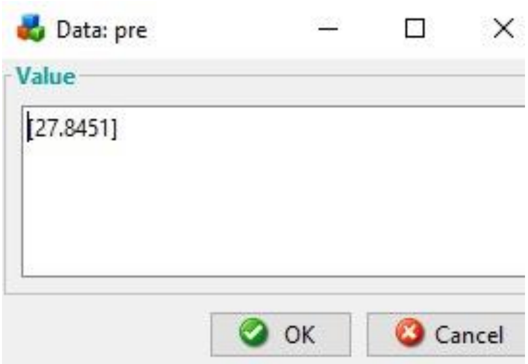

Figure 46: Result (XVII)

Table 5: Results from MATLAB

Sample	NA	R2	R5
	36.283	31.083	27.845
% change	-0.54	0.699	3.88

A novel ANN model has been presented for predicting compressive strength of concrete made with recycled concrete aggregates. The heterogeneity of RCA makes it difficult to predict the compressive strength of new concrete, which is an obstacle to the incorporation of this kind of aggregate in concrete production. In this case, 11 inputs variables have been used: the mass of cement (C), fly ash (FA), water (W), superplasticizer (SP), fine natural aggregate (FNA), coarse natural or recycled aggregate (CAN, RCA) and their properties, such as: sand fineness modulus of sand (FM of FNA), water absorption capacity (WA), saturated surface dry density of the coarse aggregate mix (SSD), maximum particle size of coarse aggregate (TM), and the resulting ANN, with 20 hidden layers, has shown to be accurate enough for a set of real data.

The proposed ANN model allows us to predict with enough accuracy the compressive strength value of a concrete from 11 input parameters, which will allow manufacturers to save time and laboratory testing when proposing new concrete dosages from recycled concrete aggregates of different sources and physical–mechanical properties.

We can notice that there is a very low variation in the values of physical experiment and the results from MATLAB. So, the above prediction model is acceptable.

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