Shear Strength Behavior of Recycled Coarse Aggregate

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Abstract - ***India is presently generating construction and demolition (C &D) waste to the tune of 23.75 million tons annually and these figures are likely to double fold in the next 7 years. C&D waste and specifically concrete has been seen as a resource in developed countries. Works on recycling have emphasized that if old concrete has to be used in second generation concrete, the product should adhere to the required strength. The recycled concrete aggregates can be defined as crushed concrete composed of aggregate fragments coated with cement paste or cement mortar from the demolition of the old structures or pavements that has been processed to produce aggregates suitable for use in new concrete. The processing, as with many natural aggregates, generally involves crushing, grading and washing. This removes contaminant materials. The resulting coarse aggregate is then suitable for use in concrete Literature survey reveals that strength primarily depends upon adhered mortar, water absorption, Los Angeles abrasion, size of aggregates, strength of parent concrete, age of curing and ratio of replacement, moisture state, impurities present and controlled environmental condition.***

Some of the studies have suggested the mix design procedure for recycled aggregates in concrete, yet a simple and cost effective method of using demolished concrete, taking into account % adhered mortar and thus calculating mix composition needs to be developed. The various methods of reinforced concrete design discussed in the literature are in the reference of normal concrete. So structural behaviour of recycled aggregate concrete needed to be studied in comparison with concrete with virgin aggregates before using it as a construction material. A detailed assessment of the various properties and different parameters affecting these properties is required for recycle aggregate concrete.

This study is to verify the shear strength behaviour of recycle aggregate concrete with respect to convention concrete. This report deals with the review of the existing literature work for the shear strength of recycled aggregate concrete and presenting some fundamentals of shear strength of concrete.

Key Words:. *Recycled coarse aggregate, coarse aggregate, Demolished structure*

1. INTRODUCTION

Any construction activity requires several materials such as concrete, steel, brick, stone, glass, clay, mud, wood, and so on. However, the cement concrete remains the main construction material used in construction industries. For its suitability and adaptability with respect to the changing environment, the concrete must be such that it can conserve resources, protect the environment, economize and lead to proper utilization of energy. To achieve this, major emphasis must be laid on the use of wastes and by products in cement and concrete used for new constructions, but the recycled material should have the behaviour incompression in tension same as that of natural material. The aim of the present study is to investigate the shear behaviour of reinforced recycled aggregate concrete (RAC) beams containing high amount of mortar and cement paste in order to contribute to establishing design method for shear by comparing with that of RC beam made of virgin aggregate. Recycling concrete from demolition project can result in considerable savings since it saves the costs of transporting concrete to the landfill, and eliminates the cost of disposal. In utilizing recycled aggregate as a structural aggregate, the inferiority in concrete quality is a major concern. Some studies concerning concrete and reinforced concrete (RC) made of recycled aggregate have been performed. The field of study exploring the properties of recycled aggregates and the basic properties of recycled concrete has developed over the last few decades, leading to a number of countries establishing standards or recommendations supporting their use. However, as a result of the small number of investigations carried out in the field of structural behavior (behavior under flexing conditions, shear, adherence, torsion, etc.), further work is required. The aim of this particular study is therefore to explore the structural shear behavior with concrete manufactured using recycled aggregates from demolished structures (RC mixes). Material is compared with conventional concrete as a reference (CC mixes). A further aim is to determine the suitability of current theoretical shear models and standards with the new material.

2. Reinforced Concrete Beam Behavior

2.1 Basic Theory

A beam resists loads primarily by means of internal moments, *M*, and shears, *V*, as shown in Fig. 1. In the design of a reinforced concrete member, flexure is usually considered first, leading to the size of the section and the arrangement of reinforcement to provide the necessary moment resistance. Limits are placed on the amounts of flexural reinforcement which can be used to ensure that if failure was ever to occur; it should be ductile, i.e. giving warning to the occupants. After the flexural proportioning of the beam it should be design for shear. Because a shear failure is frequently sudden and brittle, the design for shear must ensure that the shear strength equals or exceeds the flexural strength at all points in the beam.

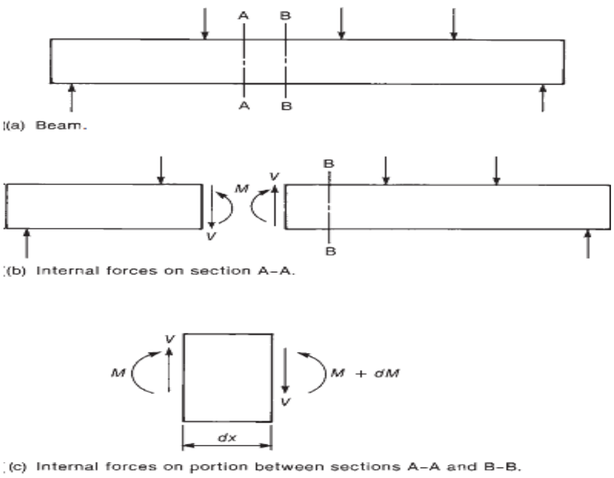

Fig: 1 Internal forces in a beam

<u>Stress in an uncracked elastic beam</u>

From the basic mechanic of materials, it is known that shear stress τ and normal stress f_x at any point, located at distance *y* from the neutral axis, are given by:

$$\tau = \frac{VQ}{Ib}$$

where *I* is the second moment of area of the section about the neutral axis, *Q* the first moment of area about the neutral axis of the portion of the section above the layer at distance *y* from the NA, and *b* is the width of the beam at the layer at which τ is calculated.

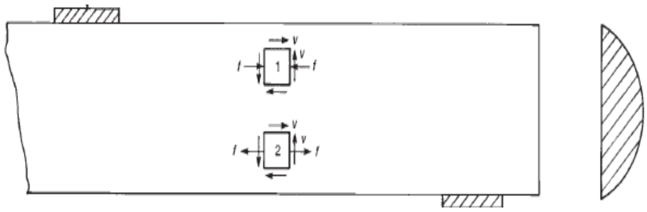

Fig: 2 Reaction↑ shear stress

The shear stresses on the top and bottom of the elements cause a clockwise couple, and those on the vertical sides of the element cause a counterclockwise couple. These two couples are equal and opposite in magnitude and hence cancel each other out.

The combined flexural and shear stresses can be resolved into equivalent *principal stresses* f_1 and f_2 acting on orthogonal planes, inclined at an angle α to the beam axis (as shown):

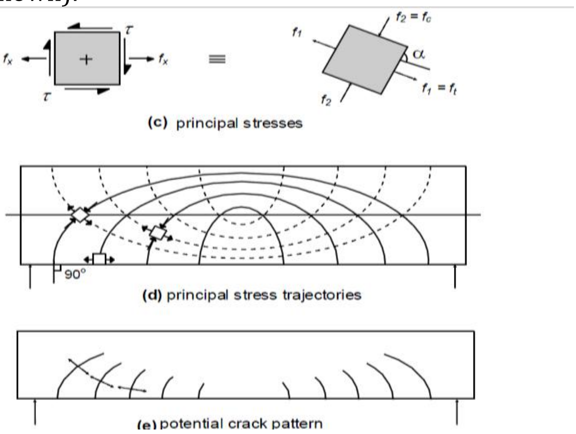

Fig: 3 Stress distributions in Homogeneous beam of rectangular section

When a flexural crack has occurred, the tensile stress perpendicular to the crack drops to zero. To maintain equilibrium, a major redistribution of stresses is necessary. As a result, the onset of inclined cracking in a beam cannot be predicted from the principal stresses unless shear cracking precedes flexural cracking.

3. Shear Behavior of Reinforced Concrete Beam

3.1 Without Shear Reinforcement

In beams without shear reinforcement, the component *Vs* is absent altogether. Moreover, in the absence of *stirrups* enclosing the longitudinal bars, there is little restraint against splitting failure, and the dowel force *Vd* is small. Furthermore, the crack propagation is unrestrained, and hence, fairly rapid, resulting in a fall in the aggregate interface forces *Va* and also a reduction in the area of the uncracked concrete (in the limited compression zone) which contributes to *Vcz*. However, in relatively deep beams, *tied–arch action* may develop following inclined cracking, thereby transferring part of the load to the support, and so reducing the effective shear force at the section.

Internal Forces in a beam without Stirrups:
There are several mechanisms by which shear are transmitted between two adjacent planes in a reinforced concrete beam.

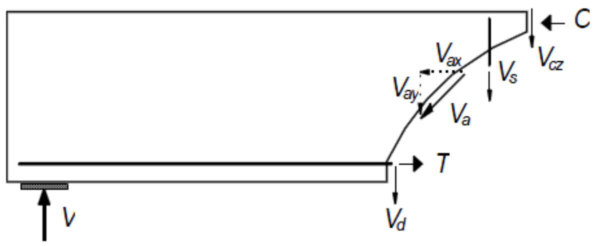

Fig: 4 Internal forces acting at a flexural-shear crack.

The transverse shear force is denoted by V, it is resisted by various mechanisms. Some of the major components of the shear force are as follows:

- Shear resistance V_{cz} of the uncracked portion of concrete;
- Vertical component V_{ay} of the 'interface shear' (*aggregate interlock*) force V_a;
- dowel force V_d in the tension reinforcement (due to dowel action);

The equilibrium of the vertical forces in the fig. results in the relation:

$$V = Vcy + Vay + Vd$$

Immediately after inclined cracking, as much as 45 to 65 percent of the total shear is carried by V_d and V_{ay} together. As the crack widens, V_a decreases, increasing the fraction of the shear resisted by V_{cy} and V_d . The dowel shear V_d, leads to a splitting crack in the concrete along the reinforcement. When this crack occurs, drops V_d, approaching zero. When V_a and V_d disappear, then all the shear and compression are transmitted in the depth above the crack. At this point in the life of the beam, the uncracked section is too shallow to resist the compression forces needed for equilibrium. As a result, this region crushes or buckles upward.

3.2 With Shear Reinforcement

In beams with moderate amounts of shear reinforcement, shear resistance continues to increase even after inclined cracking, until the shear reinforcement yields in tension, and the force *Vs* cannot exceed its ultimate value *Vus*. Any additional shear *V* has to be resisted by increments in *Vc*, *Vd* and/or *Vay*. With progressively widening crack-width (now accelerated by the yielding of shear reinforcement), *Vay* decreases (instead of increasing), thereby forcing *Vc* and *Vd* to increase at a faster rate until either a splitting (dowel) failure occurs or the concrete in the compression zone gets crushed under the combined effects of flexural compressive stress and shear stress.
Each of the components of the shear except Vs has a brittle load–deflection response. As a result, it is difficult to quantify the contributions of Vcy, Vd, and Vay. In design these are combined into two components.

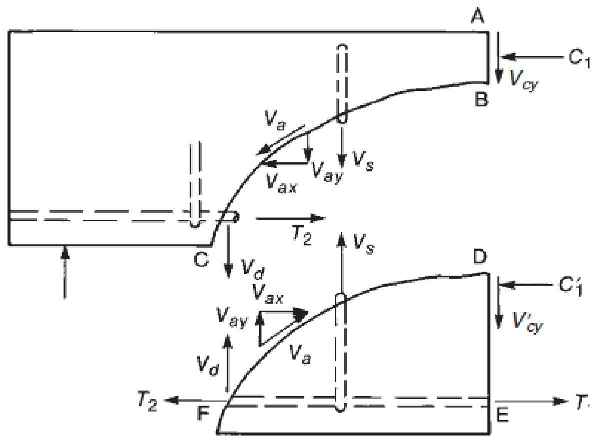

Fig:5 Internal forces in a cracked beam with stirrups.

$$Vn = Vc + Vs$$

Where Vc is called as shear strength of concrete and Vs is the shear resistance of web reinforcement.

4. Factors affecting Shear Strength

Beams without web reinforcement will fail when inclined cracking occurs or shortly afterwards. For this reason, the shear capacity of such members is taken equal to the inclined cracking shear. The inclined cracking load of a beam is affected by five principal variables, some included in design equations and others not.

- Shear Span-to-Depth Ratio (a/d): The shear span-to-depth ratio, *a/d* or *M/Vd*, affects the inclined cracking shears and ultimate shears of portions of members with *a/d* less than 2, Such shear spans are "deep" (D-regions) . For longer shear spans, where B-region behavior dominates, *a/d* has little effect on the inclined cracking shear and can be neglected.

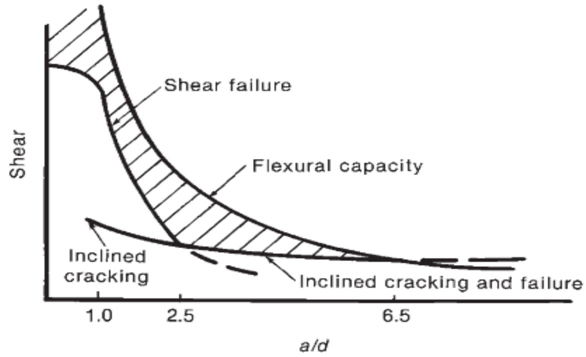

Fig:6 Effect of a/d ratio on the shear strength of beam without stirrups

- Tensile Strength of Concrete: The inclined cracking load is a function of the tensile strength of the concrete, f_{ct}. As discussed earlier, the flexural cracking that precedes the inclined cracking disrupts the elastic-stress field to such an extent that inclined cracking occurs at a principal tensile stress roughly half of f_{ct} for the uncracked section.
- Longitudinal Reinforcement Ratio, (p_t): When the steel ratio, p_t, is small, flexural cracks extend higher into the beam and open wider than would be the case for large values of p_t. An increase in crack width causes a decrease in the maximum values of the components of shear, V_d and V_{ay} that are transferred across the inclined cracks by dowel action or by shear stresses on the crack surfaces. Eventually, the resistance along the crack drops below that required resisting the loads, and the beam fails suddenly in shear.
- Coarse Aggregate Size: As the size (diameter) of the coarse aggregate increases, the roughness of the crack surfaces increases, allowing higher shear stresses to be transferred across the cracks. In high-strength concrete beams and some lightweight concrete beams, the cracks penetrate pieces of the aggregate rather than going around them, resulting in a smoother crack surface. This decrease in the shear transferred by aggregate interlock along the cracks reduces Vc.
- Size of Beam: An increase in the overall depth of a beam with very little (or no) web reinforcement results in a decrease in the shear at failure for a given f_{ck}, *pt*, and *a/d*. The width of an inclined crack depends on the product of the strain in the reinforcement crossing the crack and the spacing of the cracks. With increasing beam depth, the crack spacing and the crack widths tend to increase. This leads to a reduction in the maximum shear stress that can be transferred across the crack by aggregate interlock. An unstable situation develops when the shear stresses transferred across the crack exceed the shear strength, when this occurs, and the faces of the crack slip, one relative to the other.

5. Conclusion

Though there has been extensive research carried out on recycling yet construction industry does not have a simple and cost effective method to use the recycled aggregates in second generation concrete. Though all the above parameters as discussed are essential in evaluating and obtaining strength but still a methodology taking into consideration the quality and the % of adhered mortar would be essential if recycled aggregates have to be taken in preparation of high strength concrete. Works on recycled aggregate concrete have considered water absorption and other parameters in finding the mix proportions and strength but the structural behavior of the element made up of recycle aggregates concrete is not well documented. Therefore a detailed study is required of the structural behavior of the recycle aggregate concrete, so that suitable provision can be made in the design codes. The main objective of this study is to verify the shear strength behavior of recycle aggregate concrete with respect to convention concrete, so that we can provide suitable guideline for the shear design of recycle aggregate concrete member.

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