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Joint Shear Strength of Beam-Column Connections in Crumb Rubber Concrete

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Abstract--*Environmental pollution is one of the most critical problems in today's world. In 2008, the global production of waste tyres was estimated at around one billion each year while four billion already exist in stockpiles and landfills. These waste tyres are Non-biodegradable and release toxic substances. In Pakistan, no reliable data is available about waste tyres. Only 12% of waste tyres are used as crumb rubber products while the remaining as energy sources or landfills. The waste tyres are also used in the construction industry to replace coarse aggregate or fine aggregates in shredded form or crumb powder form. Material-level research on crumb rubber concrete has already been carried out. The present research is about to check the joint shear strength of the roof corner joint with crumb rubber as sand replacement for different ratios. The ratios used were 10%, 15%, and 20%. Three samples of Beam-column joint for each ratio of crumb rubber as a sand replacement, scaled down to one-third, were prepared. For each ratio standard cylinders were also prepared to find the compressive strength as the joint shear capacity as per ACI 352 directly related to the compressive strength of concrete. To record the stain in the beam, longitudinal steel strain gauges were installed at the beam-column interface. After curing and drying the models were tested. The cracking load and strain in beam steel were used to calculate the joint shear. The results showed that the joint shear strength decreased with the increase of rubber content in concrete. Compared to joint shear capacity the calculated joint shear strength was very low. The ACI 352 overestimates the joint shear capacity with no confinement tie inside the joint area.*

Keywords---*Crumb Rubber, Joint Shear, ACI 352, Beam-Column Connection, waste tyres,*

I. INTRODUCTION

Environmental pollution is one of the most critical problems in today's world. Every day human activities produce several waste products, which include solid waste also. One such solid waste is waste tyres. In recent decades, the growth and expansion of the Automobile industry all over the world, and the adoption of cars as the main source of transportation, creates abundant waste tyres. Waste tyres are those, which are no longer suitable for use in cars because of wear and tear. These waste tyres are recycled, or dumped in landfills, either legally or illegally. These stocks piling of waste tyres can be a source of a potential hazard. Thus disposal of waste tyres has become a significant problem in today's world

In 2008, the global production of waste tyres was estimated to be around one billion each year, while four billion already exist in stockpiles and landfills. According to RMA (Rubber Manufacturer Association), the United States alone produced 291.8 Million waste tyres in 2009 and was considered the largest producer of scrap tyres. This figure increased to 450 million in 2015 [1]. In the U.K the production of waste tyres is about 50 million each year. Every day in the U.K around 0.1 million scrap tyres are taken off vehicles [2]. In Australia, around 56 million tyres are estimated to reach their end of life every year [3]. The production of waste tyres in Malaysia is estimated to be around 8.2 million tons every year [4]. Japan, the world's largest tire manufacturer, produces 94 million scrap tyres yearly. For Pakistan, there is no reliable data available about the production of scrap tyres. The only fact known is that waste tyres are dumped in open space and some percentage is recycled and used in crumb rubber products.

These scraped tyres pose a great threat to the environment and society, as these tyres are Non-biodegradable and release toxic chemicals on burying in landfills. To counter this, scraped tyres are recycled and used in many rubber products. Scrape tyres can also be used as construction material. In the early 90s, several types of research were carried out to identify the different areas of construction where rubber tyres could be used. The list of different projects identified included, roadside pavement, road intersections, sidewalks, pathways and wheelchair ramps. In all these projects crumb rubber was replaced partially as a fine or coarse aggregate. This new form of concrete was called rubberized concrete. Rubberized concrete is a form of concrete that incorporates crumbs rubber from waste tyres as a partial replacement of natural aggregate in Portland cement concrete. The addition of rubber to concrete changes some of the mechanical properties of concrete. The elasticity and energy absorption capacity of the concrete increases when natural aggregate in concrete is replaced by rubber, which is highly desirable, in earthquake-resistant structures. The unit weight of the rubberized concrete is lower than normal concrete.

II. MATERIAL LEVEL RESEARCH

Many researchers have performed research on rubberized concrete; however, they mainly focused on mechanical properties. Very limited work has been done on the structural level. This research focuses on the shear strength of beam-column joints.

Eldin et al 1993, in the early 90s, performed several experiments using rubber tyres as a replacement for natural aggregate. The replacement was used to check the effect on the compressive and tensile strength of concrete. Both rubber chips and crumb rubber were used in the experiments to replace coarse aggregate and fine aggregate. The results indicated that there was an 85% decrease in compressive strength. The decrease in tensile strength was observed at 50% when coarse aggregate was fully replaced by an equal volume of rubber chips. For crumb rubber, the reduction in compressive strength was 65%. The failure behaviour was ductile, not brittle and the energy absorption was more in the plastic range than normal conventional concrete [5].

Neil. N.Eldin and Ahmed B.Senouci performed several experiments to check the engineering properties of rubberized concrete. They noted that the workability of concrete was in the acceptable range. The rubberized concrete did not perform well under the repeated cyclic freeze and thaw state. They also observed that the compressive and tensile strength of rubber concrete was lower than that of normal concrete. The resulting concrete absorbed more plastic energy and failure was ductile [6].

M. Ashraf and A.Naseer performed an experiment to study the thermal properties of rubberized concrete. They used the hotbox technique to evaluate thermal properties. Their experiment consisted of replacing coarse aggregate with 5%, 10% and 15% waste tyres. Standard procedures were used to check the mechanical properties of rubberized concrete. They observed that there was no appreciable change with 5% replacement, however beyond 5% replacement the change in properties was more [7].

Tushar R More and S M Dumne studied split tensile strength, flexural strength and workability of rubberized concrete. They used 0%, 3%, 6%, 9% and 12% crumb rubber to replace fine aggregate. They observed that the split tensile strength was decreased by 30% when fine aggregate was replaced by 3% rubber. This decrease continued further with the increase in rubber. They also observed that the gap between 7 days strength and 28 days decreased with the increase of rubber in concrete. The reduction in flexural strength was 40% when fine aggregate was replaced by 3% of rubber. [8].

Khatib and bayomy studied the workability of rubberized concrete. Their observations were that the slump of crumb rubber concrete decreases with the increase of rubber content. They also find out that the resulting concrete has a lower unit weight. Shredded rubber chips were used as a replacement for coarse aggregate. They used crumb rubber to replace part of the fine aggregate. [9].

III. METHODOLOGY AND EXPERIMENTAL SETUP

Beam-column joints, Scaled down to one-third, with different ratios of crumb rubber concrete were prepared, as shown in Table1. A concrete mix design of 1: 1.8: 1.6 was used to achieve the desired concrete strength of 3000psi. Three models were prepared for each ratio of crumb rubber concrete. The model dimensions and reinforcement detail is given in Fig 1. No stirrup ties were provided in the joint area. For each ratio of crumb rubber concrete 3 cylinders were also prepared to check compressive strength. To find the stain in steel, strain gauges were installed. These gauges were installed on both top and bottom steel at the beam-column interface. To record displace in the model, displacement gauges were used in both horizontal and vertical directions.

Table 1: Ratio of crumb Rubber in Sample

S No	Label	No of Samples	Rubber Replacement
1	CC	3 Samples	-
2	10%	3 Samples	10%
3	15%	3 Samples	15%
4	20%	3 Samples	20%

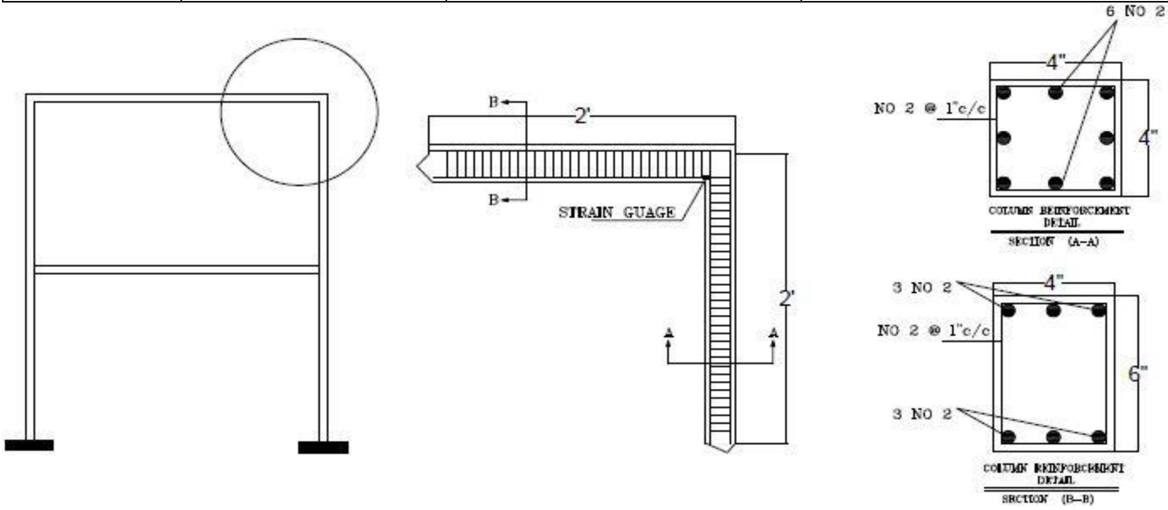

Figure 1: Reinforcement detail of Sample

After curing for 28 days the models were tested. The experimental setup is shown in Fig 2. The testing machine was located in the Structural lab, civil department UET Peshawar, Pakistan. The maximum capacity of the machine was 20 tons. To test these models two types of loading conditions were applied, Monotonic and Half cyclic. Displacement gauges were installed to record the horizontal and vertical displacement. A data log machine was used to collect data from strain gauges, load cell and displacement gauges. The first model of each ratio of crumb rubber was tested under monotonic load and the cracking load was recorded. The other two models were tested under half cyclic loading until cracks appeared. The cylinders were tested in the universal testing machine, located in UET Peshawar Pakistan, to find the compressive strength for each ratio of crumb rubber.

Figure 2: Experimental Setup (University of Engineering and Technology. Peshawar, Pakistan)

IV. CALCULATION OF JOINT SHEAR

The joint shear for the roof corner joint can be calculated by considering the equilibrium of the knee joint Fig [3]. The horizontal unbalanced force at mid-height of the joint is the joint shear [10].

$$V_{u.j} = T_n - V_{col} \qquad [1]$$

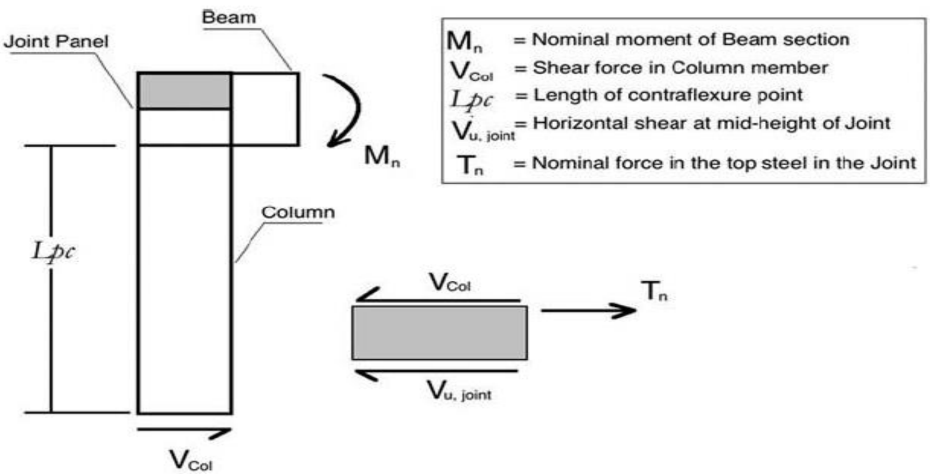

Figure 3: Equilibrium consideration at mid-height of join for joint shear calculation

Strain in the steel was used to calculate tension in steel Tn, while frame analysis was used to calculate the column shear.

V. RESULTS AND DISCUSSION

The compressive strength of cylinders for different ratios of crumb rubber as a sand replacement is shown in Table 2. It is obvious from the tables that the compressive strength decreases with the increase of rubber content in concrete.

Table 2: Ratio of crumb Rubber in Sample

S No	Rubber Replacement	No of Samples	Average Compressive Strength (ksi)
1	-	3 Samples	3.93
2	10%	3 Samples	3.63
3	15%	3 Samples	2.99
4	20%	3 Samples	2.34

The joint shear and ACI 352 joint shear capacity for models of different ratios of crumb rubber under Monotonic loading and half cyclic loading is given in Table 3, Table 4, Table 5 and Table 6.

Table 3: Joint Shear Compared with The ACI 352 Joint Shear Capacity for models with No crumb Rubber as Sand Replacement

S No	Type of Loading	Column Shear (Kips)	Strain In Steel (x10-6)	Tension In Steel (Kips)	Joint Shear (Kips)	Joint Shear Capacity As Per ACI 352(Kips)	Ratio of ACI 352 capacity to Experimental Joint Shear
1	Monotonic	15.878	1560	59.925	44.047	81.245	1.84
2	Half Cyclic	29.381	1565	60.118	30.736	81.245	2.64
3	Half Cyclic	20.026	1460	56.084	30.057	81.245	2.7

Table 4: Joint Shear Compared with The ACI 352 Joint Shear Capacity for models with 15% crumb Rubber as Sand Replacement

S No	Type of Loading	Column Shear (Kips)	Strain In Steel (x10-6)	Tension In Steel (Kips)	Joint Shear (Kips)	Joint Shear Capacity As Per ACI 352(Kips)	Ratio of ACI 352 Capacity to Experimental Joint Shear
1	Monotonic	12.817	816	31.345	18.528	72.622	3.92
2	Half Cyclic	13.695	581	22.318	8.643	72.622	8.40
3	Half Cyclic	9.398	640	24.187	15.187	72.622	4.78

Table 5: Joint Shear Compared with The ACI 352 Joint Shear Capacity for models with 15% crumb Rubber as Sand Replacement

S No	Type of Loading	Column Shear (Kips)	Strain In Steel (x10-6)	Tension In Steel (Kips)	Joint Shear (Kips)	Joint Shear Capacity As Per ACI 352(Kips)	Ratio of ACI 352 Capacity to Experimental Joint Shear
1	Monotonic	11.443	733	28.157	16.417	70.867	4.24
2	Half Cyclic	13.503	574	22.049	8.546	70.867	8.29
3	Half Cyclic	15.205	650	24.969	9.763	70.867	7.258

Table 6: Joint Shear Compared with The ACI 352 Joint Shear Capacity for models with 20% crumb Rubber as Sand Replacement

S No	Type of Loading	Column Shear (Kips)	Strain In Steel (x10-6)	Tension In Steel (Kips)	Joint Shear (Kips)	Joint Shear Capacity As Per ACI 352(Kips)	Ratio of ACI 352 Capacity to Experimental Joint Shear
1	Monotonic	17.022	526	20.205	3.183	62.69	19.69
2	Half Cyclic	9.054	328	12.599	3.545	62.69	17.68
3	Half Cyclic	9.140	295	11.332	2.191	62.69	28.61

It is obvious from the above tables that the joint shear strength decreases with the increase of rubber content in concrete. Fig 4 shows the comparison of experimental joint shear and ACI 352 joint shear capacity for each ratio of crumb rubber concrete, under Monotonic and half cyclic loadings.

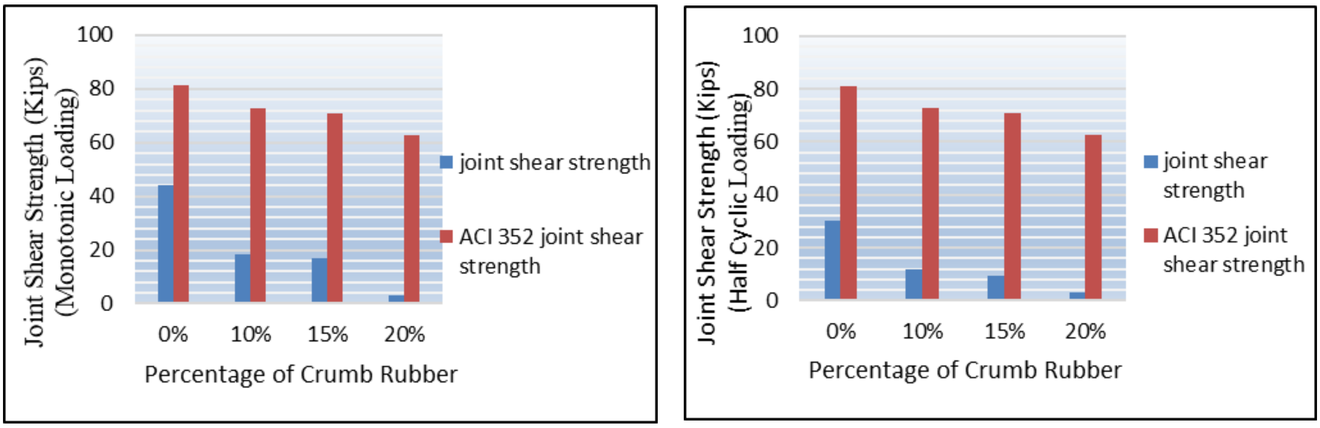

Figure 4: Joint Shear compared with the Joint Shear Capacity as Per ACI 352 for Monotonic and half Cyclic Loading.

The difference between ACI 352 joint shear and experimental joint shear increases with the increase of rubber content. This difference is shown in Fig 5.

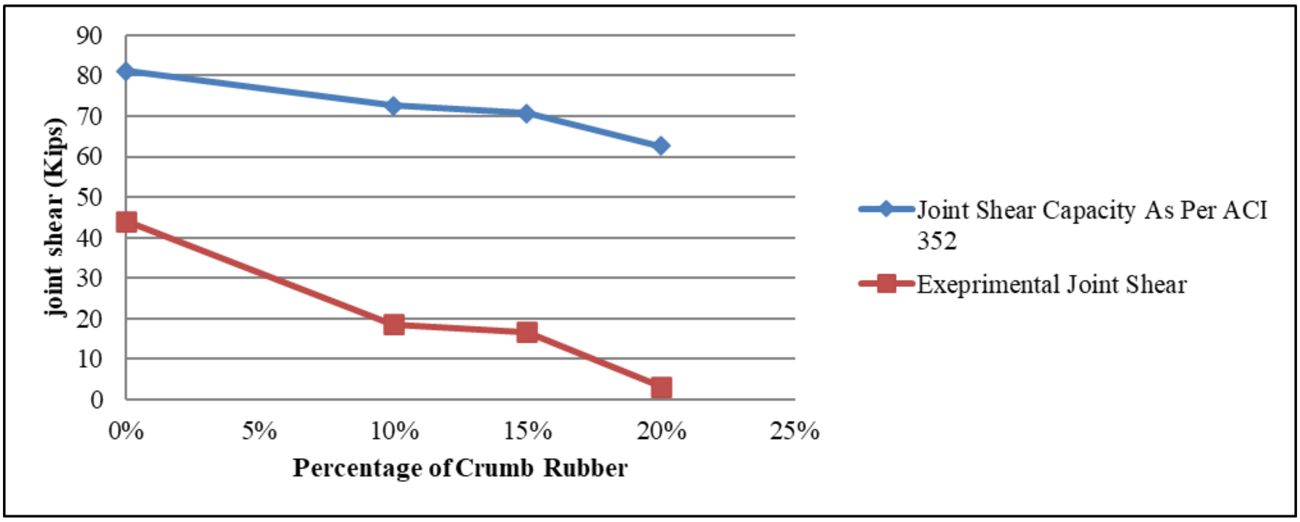

Figure 5: Joint Shear Compared with the Joint Shear Capacity as Per ACI 352

VI. CONCLUSIONS

- The Joint Shear Capacity decreases with the increase of crumb rubber content in concrete.
- ACI 352 overestimates the shear capacity of beam-column joints having no confining ties.
- The difference between ACI 352 joint shear and experimental joint shear increases as rubber content increases.
- The increase of rubber in concrete decreases the compressive strength of the resulting concrete.

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