A Review on Behaviour of Beam Column Joint Using EAF Steel Slag Concrete

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ABSTRACT

The amount of industrial waste generated and the overexploitation of quarries worldwide are becoming one of the serious environmental problem. Electric Arc Furnace (EAF) steel slag is currently used for asphalt concrete pavements in many countries but huge quantities of this material are still landfilled. Reusing the slag as recycled material in the construction industry not only helps in the reduction of the amount of waste disposed off but can also bring down the consumption of natural aggregates. EAF slag is the secondary product of the steel production process and is procured after the separation of molten steel from impurities. In this review paper, the impact of using EAF concrete on the structural behavior of internal beam-column joints and also the resisting mechanism of these joints are studied. A parametric study on the structural performance of EAF concrete compared to conventional concrete in terms of the load-carrying capacity, energy dissipation and strength attained by the joint in failure condition is made.

Keywords: Beam column Joint, EAF Concrete

1 Introduction

India is the second-biggest crude steel producer in the world. According to the data of the World Steel Association, crude steel production in India in 2019 was estimated at 111.2 million tons which resulted in 12 million steel slag tons. This leaves a certain remark in the enormous quantity of slag produced. The steel slag is generally discarded worldwide and is becoming an important problem due to the scarcity of land. The problem is further added as there are no adequate specific regulations or norms for the disposal and control of slag generation. EAF slag is obtained as a steel production process byproduct and when Electric Arc Furnace is used instead of Basic Oxygen Furnace (BOF). The advantages of using EAF compared to BOF is mainly of the following reasons: (i) material consumption of BOF process is higher, (ii) energy consumption of BOF process is 2.8 times greater than that of EAF process, (iii) low carbon emission as in EAF process and (iv) cost of production is lower.In Indian practice, a beam-column joint is not efficiently designed mainly due to economic considerations.

Beam-column joints are critical regions in the moment resisting RC frame, specifically considering combined loading conditions. During earthquakes, the failure of RC frames occurs primarily because of large shear in joints resulting in the entire breakdown of the structure. The design of the joints can be avoided as if the structure is mainly subjected to only gravity load. Adequate detailing and design of joints have to be ensured and controlled to improve the strength and ductility to resist large deformations caused due to earthquakes or wind. The review evaluates the replacement of conventional cement concrete with EAF steel slag and their effect in any structural member i.e. beam column joints.

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2 Need for the study

Beam column joints have a significant influence on the response of the structure. The analytical study conducted on the behavior of this joint gives a proper understanding of its structural behavior and also its importance in a structure subjected to gravity and earthquake loads. By incorporating EAF concrete in this study, the question of whether this sustainable construction technique is acceptable for a critical region like a beam-column joint can be explained. It also gives a better idea about the potential use of EAF steel slag as recycled aggregate in critical regions like beam-column joints thereby contributing to sustainable construction.

Fig 1. Stockpile of EAF steel slag (Source: www. ien.com)

3 Studies on EAF concrete

Manso et al. (2004) conducted experiments on concrete with fine and coarse aggregates replaced by EAF steel slag. The slag obtained was crushed and stabilized to make suitable mortars. Several mixes were designed to analyze their strength and properties. Durability and environmental behaviour were also found out by conducting accelerated ageing, soundness, and leaching tests. Results indicated that the durability of EAF concrete showed an acceptable behaviour against aggressive environments especially in the geographic region where the winter temperature hardly ever falls below 0℃.

Manso et al. (2006) conducted tests to evaluate the internal expansivity of the slag and its resistance to environmental agents, ice and moisture were made. The results showed that the EAF slag concrete performance was similar with conventional concrete in terms of strength and in terms of its durability. The high porosity of EAF slag is the main disadvantage when it comes to concrete making. The leaching test showed a cloistering effect of concrete on the products present in EAF slag which are toxic.

Rajan (2014) evaluated the strength of concrete of M20 mix made with steel slag with the replacement of fine aggregate. The replacement of sand with steel slag was carried out partially for variable percentages of 10%, 20%, 30%, 40% and 50% in weight of sand. Experimental studies like flexural strength test , compression test, tensile strength test and stress-strain test were carried out. The final results showed that the compressive strength, tensile strength and flexural strength increase with the increase in the percentage of steel slag up to 30% by weight of fine aggregate. The stress-strain graph showed that 30 % of steel slag replaced with M20 concrete is similar to traditional M20 concrete.

Faleschini et al. (2015) characterized the EAF slag by the chemical, physical and microstructural properties analysis. Varying cement content and also with silica fume addition, Three EAF concrete is compared with a reference concrete, to identify a convenient mix design to reach a concrete strength class between C50/60 and C60/75. Mechanical strength was evaluated by analyzing compressive and tensile strength, and elastic modulus. After the failure of the specimens, a complementary microstructural analysis was performed to analyze the morphology of the interfacial transition zone. The resulting in the use of EAF slag in concrete allows reaching higher compressive strength than with coarse natural aggregates.

Rondi et al. (2015) focused on experimental studies evaluating the properties and environmental suitability of EAF steel slag and the mechanical behaviour of concrete made with fully EAF slag as aggregate. Several tests were carried out on fresh and aged slag. The leaching behaviour and volumetric stability were also investigated. The mechanical properties of EAF concrete were compared to that of the reference concrete having only natural aggregates. The result showed mechanical properties compatible with their use in civil constructions by using EAF steel slag as aggregate.

Sekaran et al. (2015) studied the physical, mechanical and durability properties of EAF slag concrete in addition to fly ash. Tests were conducted on three specimens: (i) conventional concrete with no material substitution, (ii) 30% replacement of cement with fly ash and (iii) 50% replacement of coarse aggregate with EAF oxidizing slag and 30% replacement of cement with fly ash. The results showed greater strength and durability characteristics compared to the other two mixes.

Lee et al. (2019) performed a comparative assessment of mechanical properties of concrete containing EAF oxidizing slag, steelmaking slag and granulated blast furnace slag. The factors considered for measurement are shrinkage, compressive and split-cylinder tensile strength, initial and final setting of the slag concretes. It was found that replacement delayed the hydration reaction at early ages, with no major problems in setting time, shrinkage or strength development found.

4 Studies on External beam-column joints

Beam column joint connections is used to transfer the loads from one member to another. Failure of Steel structures mainly occurs due to the accumulation of stresses at the connection. The actual behavior of the structure is very much dependent on the connection and joint characteristics as same as the individual component elements making up the structure. This signifies the solution that to be made.

Many works showed the feasibility of using Electric Arc Furnace slag to produce structural concrete. Faleschini et al. (2017) conducted experiments on exterior beam-column joint made of EAF concrete where EAF was used as a replacement for coarse aggregates. A horizontal reversed cyclic quasi-static load was applied with displacement control at the top of the column to correlate the measured displacements of the joint to the inter-story drift. The axial loads corresponding to the gravity load was applied at the top of the column and it was kept a constant. The results evidenced that joints made with EAF concrete attained higher loads than the control specimen where conventional concrete was used. Also, a reduced cracking pattern was observed for EAF beam-column joints.

A numerical study was carried out on slotted beam-column welded connection by Aslam et al. (2005) to understand its behaviour. The actual behaviour of the structure is as much dependent on the connection and joint characteristics. Therefore, to minimize the stresses at connection, slotted beam-column connections were analysed using Ansys. The stress distributions at the slotted beam-column connection were minimized by separating the beam flanges from the beam web within the region of the connection by using beam web slots and welding the beam web to the column flange, The slotted beam-column connection was considered to be very cost-effective for new construction and for retrofitting existing steel frames.

A method proposed by Kotsovou and Mouzakis (2012) for the seismic design of external beam-column joints by considering that the load transfer mechanism is mainly by diagonal strut mechanism. The research was intended not only to verify the validity of the proposed method but also to identify means for its implementation that will maximize its effectiveness. The results showed that the proposed method produced design solutions that fully satisfy the code performance requirements of strength, stiffness and energy dissipation capacity.

Prasanna et al. (2017) studied the experimental behaviour of M20 concrete in a beam-column joint subjected to seismic loading by using 1.5% steel fibre. The specimens were casted and tested under cyclic loading and reverse cyclic loading. The results indicated that fibre reinforced beam-column joint with 1.5% fibre has better ductility, load carrying capacity, energy dissipation and strength by 10% more than the conventional reinforced beam-column joint.

Venkatesan et al. (2016) conducted an experimental and analytical study on the seismic performance of exterior beam-column joints strengthened with unconventional reinforcement detailing by applying reversed cyclic loading at the beam end. Based on the joint reinforcement detailing, specimens were divided into two groups: the first group of three non-ductile specimens and the second group of three ductile specimens. The results indicated that hysteresis simulation was satisfactory for both un-strengthened and ferrocement strengthened specimens.

Kadarningsih et al. (2016) analytically studied in detail the various arrangements of reinforcement in beam-column joint. Due to the limitation offered by concrete in resisting shear stress, the need for a large amount of steel bars in reinforcement in joints is to be ensured. This causes congestion in that area which raises the problem of reinforcement installation. As a solution to this problem, King cross steel profiles were used as a replacement for the transverse reinforcement.

Sarkar et al. (2007) reviewed the design procedures of the RC beam-column joint based on three international codes of practice: ACI 318M:02, NZS 3101:1995 and EN 1998-1:2003. It is inferred that the New Zealand code gives the most conservative recommendations followed by Eurocode. The ACI code, although relatively less conservative, gives many practical recommendations.

Uma and Jain (2006) reviewed the recommendations of international codes ACI 318M:02, NZS 3101:1995 and EN 1998-1:2003 regarding design and detailing aspects of beam-column joints. It was observed that ACI required smaller column depth compared to the other two codes based on anchorage conditions. New Zealand code and Eurocode consider the shear stress level to obtain the required stirrup reinforcement whereas ACI provides stirrup reinforcement to retain the axial load capacity of column by confinement.

Patil and Manekari (2013) focused on various parameters for monotonically loaded exterior and corner reinforced concrete beam-column joint by stiffness variation of the joint and support conditions. Load deformation graphs are plotted for these conditions and it was concluded that as the load increases displacement, minimum stress and maximum stress also increases. Also, for fixed support conditions for corner and exterior joint the displacement, minimum stress and maximum stress values were minimum as compared to hinge support condition.

Elmasry et al. (2018) modelled an exterior beam-column joint to simulate the behaviour of such joints in older gravity load-designed RC frame structures. Several specimens were studied for an un-strengthened case and strengthened cases with different techniques like CFRP sheets and steel jackets. The stress and deformation results were evaluated and compared for each case. Results showed that the beam-column joint with CFRP strengthening can increase their structural stiffness, strength and energy dissipation capacity in relation to other techniques.

5 Studies on internal beam-column joints

Oka et al. (1992) conducted a study on the design provisions in high seismic regions for interior beam-column joints using high strength concrete subjected to cyclic loading. The behaviour of specimen such as joint shear, hysteresis characteristics, failure modes etc., and compared with those of normal strength concrete. He showed that increase in horizontal joint shear was not proportional to that of concrete compressive strength. Increasing the amount of tensile reinforcement, the joint shear capacity increased by 0-10%. This study doesn't show the effect of column and beam reinforcement on its effect on joint shear strength.

Li et al. (2009) conducted study on seismic behavior of non seismically detailed interior beam column joint and the effects of axial compression load and eccentricity on. Axial loads varying from zero to high magnitude and quasi-static cyclic loading were used for analysis. The analysis mainly focused on performance in terms of lateral load capacity,stiffness, , drift, energy dissipation capacity, joint shear strength. The result showed that the attainment of low stiffness and strength was related to the bond deterioration of the longitudinal bar in the joint core. He focused on the effect of column axial loading on bonding strength and found the bond resistance reached its maximum value. The presence of axial compression loading and its implication with energy dissipation capacity and stiffness of joints. Found that after bond resistance reached its maximum value and degradation started, the presence of axial compression loading has very critical effects on energy dissipation capacity including stiffness of joints.

Muhsin et al. (2011) studied a new model for estimating the shear strength of reinforced concrete interior beam-column connections. The study modified the effective area of joint panel and effective concrete strength mainly on interior bam column joint and the influence of transverse reinforcement in the joint panel and axial force in columns are studied. This method is compared to the ACI and AJI design codes and a shear positive correlation were found between joint shear strength and concrete strength

The beam-column joint's seismic performance of can be enhanced with improved details in the joints and its behavior is studied by Hwang et al. (2015). Cyclic loading tests were analysed for beam-column connection of which joint detailing was improved by placing additional 45 and 90 degrees hooked bars by relocating the plastic hinge zone to a distance of 0.5 to 1.0 times the beam depth from the column face. The study showed enhanced performance in the design of beam-column joint by redefining the details of additional bars.

Sheela and Geetha (2012) experimentally studied the behaviour of strengthened beam column joints under static as well as cyclic loading. Strengthening materials used were ferrocement, Glass Fibre Reinforced Polymer (GFRP) and Carbon Fibre Reinforced Polymer (CFRP). Found that the specimen strengthened with GFRP shows better performance in terms of energy absorption capacity, ultimate load, moment rotation characteristics, ductility and strength-cost ratio when compared to other strengthened specimens.

Pan et al. (2017) studied about the impact of local joint deformation on the worldwide frame response during a holistic analysis by implementing a joint model. The joint model simulates the joint shear deformation and bars slip effects. The study also considers concrete confinement effects. Summarizes that beam-column joint deformations by shear cracking and bond-slip are major contributors to lateral story drifts. The analysis procedure by new joint element was verified with nine interior beam-column joint subassemblies. Verification focuses to work out the the implementation accuracy and finally the improvements over the first program, the specimens considered covered various failure mechanisms, reinforcing ratios and material properties. The analytical responses of the specimens was compared with the experimental responses in terms of its load-displacement responses, peak loads, loads initially beam yielding, failure modes, crack widths, and joint panel shear distortions. The joint implementation developed with interior joints subjected to monotonic loading.

Najafgholipour et al. (2017) focused on the importance of joint shear failure influences on strength and stability of RC moment-resisting frames, a finite element modeling is completed which studied joint shear behaviour. Nonlinear finite element analysis (FEA) of RC beam-column connections is performed to found out the failure mode in terms of joint shear capacity, deformations and cracking pattern. An FEA model, capable of appropriately modelling the concrete tensile cracking, stress-strain behaviour and compressive damage of concrete and indirect modelling of the steel-concrete bond was done. The configuration of the numerical model is implemented in finite element analysis software ABAQUS. To define the nonlinearity behaviour of concrete material was defined by applying the concrete damage plasticity to the numerical model as a distributed plasticity over the whole geometry. Verification of finite element model with experimental results of two non-ductile beam-column connections, one exterior and one interior which are vulnerable to joint shear failure is made. Found that the comparison with experimental and numerical results indicates that the FE model is done in a position to simulate the performance of the beam-column connections and is during a position to capture the joint shear failure in RC beam-column connections.

Jel lee et al. (2018) focuses on international existing criterion and developed a simplified minimum joint depth equation. The applicability of the equation is done with the cyclic testing conducted in East Asian countries for earthquake-resistant structures where Grade 490, 590, and 690 MPa reinforcement are used. Beam-column joints which satisfied the proposed equation demonstrates the hysteresis behavior, satisfactorily showed an inter-story drift of 4%. A bigger hc/db ratio and lower joint shear stress showed better performance of joints under cyclic loading. Higher joint shear stress may end in initial joint shear failure, which causes building collapse and must to be avoided. A smaller hc/db ratio results in excessive bar stick within the joint core and pinching hysteretic performance, but not caused any local collapse. The minimum hc/db ratios specified by codes and standards for special moment frames have supported the expected hysteresis behavior at a design inter-story drift. Relatively pinched hysteresis behavior are often observed within the beam-column joints with bond deterioration along the beam bars passing through the joint. Such damage within the joint core is unlikely to be easily repairable and thus should be avoided during a design basis earthquake event. Zhang et al. (2020) present analytical and experimental investigations on Reinforced Concrete beam-column joints with incorporated engineered cementitious composite (ECC) material within the beam–column joint region. Six exterior and interior beam-column joints made with different reinforcement detailing within the joint cores were finally designed and then tested. Quasi-static lateral cyclic loadings and representative column axial loading were applied to them. Hysteresis behaviour, joint shear stresses, crack patterns, energy dissipation capacity and strain profiles of the reinforcements was examined. To research the joint shear force transfer mechanism, done with the development of an analytical truss model for ECC joints. The joint transverse reinforcement effect was also studied for the analytical model. Results indicated that higher column axial loading was critical to the performance of the joints, above an axial load ratio equal to 0.3 for joints with higher strength ECC. The study also signifies the necessity of joint transverse reinforcements to avoid joint shear failure.

6 Conclusion

The literature review conducted on beam-column joints showed that most of the studies were based on either conventional RC beam-column joints or fibre reinforced joints. Different studies on the international codes of seismic design of beam-column joint divulge the fact that there is an urgent need of reforming the Indian codes of practice. After conducting the literature review on Electric Arc Furnace concrete, it is understood that EAF concrete exhibits similar or better (in certain cases) structural performance when compared to conventional concrete i.e properties such as compressive strength, durability, shrinkage, failure modes, hysteresis behavior, and higher load capacity. Joints made with less cement content and replacing with EAF steel slag considered more environmental susceptible, displayed good global and local performances. Experimental and analytical studies on EAF concrete incorporated in an interior beam-column joint (or any structural component) is very limited. Hence the behaviour of the same in joints is still a grey area and yet to be studied.

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References

ACI 318M-11 (2011), "Building Code Requirements for Structural Concrete and Commentary", Reported by ACI Committee 318, American Concrete Institute, Farmington Hills, Michigan.

ACI 352R-02 (2002), "Recommendations for Design of Beam-Column Connections in Monolithic Reinforced Concrete Structures", Reported by Joint ACI-ASCE Committee 352, American Concrete Institute, Farmington Hills, Michigan.

Manso J. M., Javier J., Gonzalez, Polanco J. A., (2004). "Electric Arc Furnace Slag in Concrete", Journal of Materials in Civil Engineering ASCE, Vol. 16(6), pp 639-645.

Manso J. M., Polanco J. A., Losanez M., Gonzalez J. J. (2006). "Durability of concrete made with EAF slag as aggregate", Cement and Concrete Composites, Vol. 28(6), pp 528-534.

Rajan M. S., (2014). "Study on Strength Properties of Concrete by Partial Replacement of Sand by Steel Slag", International Journal On Engineering Technology and Sciences, Vol.1(6), pp 96-99.

Faleschini F., Brunelli K., Zanini M. A., Dabala M., Pellegrino C. (2016). "Electric Arc Furnace Slag as Coarse Recycled Aggregate for Concrete Production", Journal of sustainable metals and materials, Vol. 2, pp 44-50.

Rondi L., Bregoli G., Sorlini S., Cominoli L., Collivignarelli C. (2015). "Concrete with EAF steel slag as aggregate: A comprehensive technical and environmental characterization", Composites, Vol.90, pp 195-202.

Sekaran A., Palaniswamy M., Balaraju S. (2015). "A Study on Suitability of EAF Oxidizing slag in Concrete: An Eco-Friendly and Sustainable Replacement for Natural Coarse Aggregate", The Scientific World Journal, Vol. 15, pp 1-8.

Rajasekhar K., Praveenkumar M., (2017). "Stress-Strain Behaviour of Confined Normal Grade Concrete", International Journal of Professional Engineering Studies, Vol. 8(3), pp 271-282.

Lee J., Choi J., Yuan T., Yoon Y., Mitchell D. (2019). "Comparing Properties of Concrete Containing Electric Blast Furnace Slag and Granulated Blast Furnace Slag", Materials, Vol. 12(9), pp 1371-1382.

Faleschini F., Hofer L., Zanini M. A., Benetta M., Pallegrino C. (2017). "ExperimentalBehavior of Beam-Column Joints Made with EAF Concrete Under Cyclic Loading", Engineering Structures, Vol. 139, pp 81-95.

Mirza O., Uy B. (2010). "Finite Element Analysis of the Behaviour of Composite Beam-to-Column Connections Subjected To Seismic Loading", Structures Congress 2010, pp 3431-3442.

Aslam, Nath Y., Vijai K., Udayasankar S. (2005). "Numerical Studies on Slotted Beam-Column Connection", Structures Congress 2005, pp 1-8.

Kotsouvou G., Mouzakis H. (2012). "Exterior RC Beam-Column Joints: New Design Approach", Engineering Structures, Vol. 41, pp 307-319.

Ganesan N., Indira P. V., Abraham R. (2007). "Steel fibre reinforced high performance concrete beam-column joints subjected to cyclic loading", ISET Journal of Earthquake Technology, Vol. 44, pp 445-456.

Unal M., Burak B. (2013). "Performance of Beam-to-Column Connection of a Well-Detailed RC Moment Frame Building under Pseudo-dynamic Loading", Journal of Structural Engineering, Vol.139(6), pp 886-896.

Prasanna K., Ramasubramani R., Anandh K. S., Saisabarish, Maddu V. K. (2017)."Strengthening of Beam-Column Joint With Steel Fibre Reinforced Concrete Under Seismic Loading", Earth and Environmental Science, Vol. 80, pp 1-11.

Venkatesan B., Ilangovan R., Jayabalan P., Mahendran N., Sakthieswaran N., (2016). "Finite element analysis (FEA) for the beam-column joint subjected to cyclic loading was performed using ANSYS", Scientific Research Publishing, Vol. 7(8), pp 1581-1597.

Kadarningsih R., Satyarno I., Muslikh., Triwiyono A. (2017), "Analysis and Design of Reinforced Concrete Beam-Column Joint Using King Cross Steel Profile", Sustainable Civil Engineering and Construction Materials, Vol.171, pp 941-956.

Sarkar P., Agrawal R., Menon D. (2007). "Design of RC Beam-Column Joints Under Seismic Loading- A Review", Journal of Structural Engineering, Vol.33(6), pp 449-457.

Uma S. R., Jain S. K. (2006). "Seismic design of beam-column joints in RC moment resisting frames – Review of codes", Structural Engineering and mechanics, Vol. 23(5), pp 579-597.

Patil S. S., Manekari S. S. (2013). "Analysis of Reinforced Beam-Column Joint Subjected to Monotonic Loading", International Journal of Engineering and Innovative Technology, Vol.2 (10), pp 149-158.

Elmasry M. I. S., Abdelkader A. M., Elkordy E. A. (2018). “An Analytical Study of Improving Beam-Column Joints Behaviour Under Earthquakes”, Sustainable Civil Infrastructures, pp 487-500.

Bing Li., Pan T.C. (2009). “Effect of axial compression load and eccentricity on seismic behaviour of non seismically detailed interior beam wide column joints” Journal of Structural Engineering,Vol. 135, No. 7, July 1, 774–784.

Muhsin B. A., Umemura H. (2011). “New model for estimation of shear strength of reinforced concrete interior beam column joints”, Twelfth east Asian pacific conference on structural engineering and construction, Vol. 45, No. 5, March 1, 244–283.

Sheela S., Geetha B. A. (2012). “Studies on the Performance of RC Beam-Column Joints Strengthened Using Different Composite Materials”, Journal of Infrastructures Engineering, Vol. 93, pp 63-71.

Pan Z., Guner S., Vecchio F. J. (2017). “Modeling of interior beam column joints for nonlinear analysis of reinforced concrete frames”, Journal of Engineering structures, Vol. 39, pp 868-876.

Najafgholipour M. A., Dehghan S.M., Dooshabi ., Niroomandi A. (2017). “Finite element analysis of reinforced concrete beam-column connections with governing joint shear failure mode”, Latin American Journal of solids and structures, Vol 14, pp 1200-1225.