

Utilizing Industrial Metal Wastes in One-Way Ribbed Reinforced Concrete Panels

Utilización de desechos metálicos industriales en los paneles de hormigón armado nervados unidireccionales

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PAG 246-256

Abstract

The elimination of metal waste generated during the initial manufacturing processes of industrial plants and workshop machines still a big problem. The current investigation dealt with adding the metal wastes produced by machinery processing such as iron filings powder, iron turning lathe, and aluminum turning lathe to improve the structural performance of oneway ribbed slab (RS) panels. Two types of concrete were considered in this work; Ferro cement (FER) and self-compacting concrete (SCC). The reinforced concrete panels with iron filings powder and iron turning lathe showed an increase in the ultimate load and a decrease in the central deflection, while the panels with aluminum turning lathe revealed an opposite behavior. The significant effect of using metal wastes is the superior resistance to crack propagation by increase the bond between fibers and cement mortar across the cracks. Adding the metal wastes with fine particles improves the concrete strength providing the workability must be controlled. Using the lathe as an iron fiber with a specific shape factor has a side effect due to fiber balling in the concrete mix. Also, high percentages of filings iron powder cause agglomerate the powder particles due to magnetic attraction forces.

Keywords: Recycled material, Waste, Fibre-reinforced concrete, Ferro cement, Self-compacting concrete

Resumen

La eliminación de los desechos metálicos generados durante los procesos iniciales de fabricación de plantas industriales y máquinas de talleres sigue siendo un gran problema. La investigación actual se ocupó de agregar los desechos metálicos producidos por el procesamiento de maquinaria, como el polvo de limaduras de hierro, el torno de hierro y el torno de aluminio para mejorar el rendimiento estructural de los paneles de losa nervada unidireccional (RS). Dos tipos de concreto fueron considerados en este trabajo; Ferrocemento (FER) y hormigón autocompactante (SCC). Los paneles de hormigón armado con polvo de limaduras de hierro y torno giratorio de hierro mostraron un aumento en la carga final y una disminución en la desviación central, mientras que los paneles con torno giratorio de aluminio revelaron un comportamiento opuesto. El efecto significativo del uso de los desechos metálicos es la resistencia superior a la propagación de grietas al aumentar la unión entre las fibras y el mortero de cemento a través de las grietas. Agregar los desechos metálicos con partículas finas mejora la resistencia del concreto, siempre que se controle la trabajabilidad. El uso del torno como fibra de hierro con un factor de forma específico tiene un efecto secundario debido a la formación de bolas de fibra en la mezcla de concreto. Además, los altos porcentajes de limaduras de polvo de hierro provocan la aglomeración de las partículas de polvo debido a las fuerzas de atracción magnética.

Palabras clave: Material reciclado, Residuos, Hormigón reforzado con fibra, Ferrocemento, Hormigón autocompactante

1. Introduction

Recycling exists in nature in several ways. Droppings some organisms, consider the main food for other living organisms. Humans carried out the waste retrieval process since the ancient ages, where he dissolved the metal materials to be converted into new other tools. Various types of waste material have been used in concrete products such as rubber, glass, polyethylene, ferritic, etc. The substantial source of metal waste is collected from the workshops and industrial plants that deal with metal raw material. This manufacturing machines residual is almost ready to use and enter the structural industry because of the suitable sizes and shapes that depend on the type of industries, as well as without the need of recycling energy. So, the metal waste that is sorted and assembled became a relatively high value with very minimum cost, particularly copper, aluminum, lead, and iron waste. The present study investigates the effect of the addition of metal waste like iron filings, iron turning lathe, and aluminum turning lathe on the structural behavior of Ferro cement and self-compacting concrete (SCC) one-way ribbed slab panels.

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(Asamoah and Kankam, 2009) were performed tests on twelve concrete slabs act in oneway action, reinforced with steel bars milled from scrap metals. The slabs were simply supported and subjected to distributed line loads on the third span. Failure modes were predicted as; tension bars yielding and flexural crushing in the concrete. The factor of safety obtained from the results was approximately (1.3) and (0.94) against cracking and collapse respectively.

(Murali et al., 2012) study the effect of adding waste materials involved a waste of turning lathe, caps of the soft bottle, empty tins, steel powder from the workshops.

The ratio of the used waste as fibers was (1%) of the concrete weight. All the used waste of turning lathe, empty tins, bottle caps were formed as rectangular strips of dimensions (3) mm by (10) mm. By comparison the results with conventional concrete, it was found that the concrete block units integrated with the steel powder increased by 41.25% and 40.81% in compressive and tensile strengths respectively, while the flexural strength of concrete increased by 25.88% when the block units reinforced with soft drink bottle caps.

(Awanish and Shukla, 2013) tried to determine the strength characteristics of the concrete mixtures made from the recycled aggregates with the waste produced by Computer Numerical Control (CNC). The study aimed to determine and compare the influence of different percentages of CNC waste mixed with recycled aggregates on the concrete strength. A percentage of 2% of CNC waste mixed with the recycled aggregate exhibited a gradual increase up to 50% in the compressive strength.

Experimental studies on the steel scrap fiber reinforced concrete (SSFRC) were carries out by (Shrivastava and Joshi, 2014). Experiments showed that the addition of the steel scrap enhanced the mechanical properties of hardened concrete. It was found an increase in the compressive, flexural, impact, fatigue, and split tensile strengths by addition (0.5 - 2) % of the scrap content. Flexural strength increased by (40%) and considerable increase in the tensile and compressive strength was observed when compared the ordinary concrete to the (SSFRC).

(Sezhiyan and Rajkumar, 2014) present a study to use the glass powder instead of cement content to assess the pozzolanic activity of the fine glass powder in the concrete. The authors found that the pozzolanic behavior was evident when the glass waste was finer than 100 μ m. The glass powder reacts with the lime at an early stage of hydration to form an extra calcium silicate hydrate (CSH) gel thereby forming a denser cement matrix. In the presence of glass particles, the early consumption of alkalis lessens alkali-silica reaction and then increases the concrete durability.

(Aghaee et al., 2015) used the steel wires residues taken from the steel reinforcement which wastes in buildings and infrastructure projects in structural lightweight concrete. The percentages of the used fibers in concrete specimens were (0.25%), (0.5%) and (0.75%) of the concrete volume. The authors concluded that the wires waste could be used as an appropriate alternative instead of the steel fibers in structural lightweight concrete.

(Satyaprakash et al., 2019) investigated the suitability of a complete replacement of the fine aggregate by the iron filings to reduce the sand mining effect on the environment. The authors found a significant increase in compressive and split tensile strengths by completely replacing the sand with the iron filings.

Ribbed slab panels give considerable extra strength in one or two directions and the span limits of ribbed panels are considerably longer than the solid panels. The ribbed system is considered more economical than the other slab system types by providing ribbed beams that are constructed by using hollow blocks, removable forms, or permanent or removable void formers.

The one-way ribbed slab panel can be used to reduce a self weight of the concrete panel and therefore to minimize the size of columns, footings, and other load-bearing elements. Two types of reinforced concrete were used in this work; Ferro cement (FER) and selfcompacting concrete (SCC), and each type involves five ribbed panels.

The mineral waste with different shapes of aspect ratio is suitable to use with these types of concrete because the Ferro cement thin concrete section may not usually need to use large diameters of main reinforcement as well as, the self-compacting concrete is characterized as self-consolidating which used with dense steel reinforcement.

The scope of this study covers ten one-way ribbed reinforced concrete panels to study the effect of the experimental parameters. Three types of industrial machinery waste, iron filings, iron turning lathe, and aluminum turning lathe were added to the concrete mix by different percentages. All one-way ribbed panels were cast and tested under uniformly distributed loading on the top surface.

2. Materials and Methods

2.1 Metal Wastes

Wastes are unwanted, unusable, or harmful residuals materials. Waste is any material that is discarded after primary use, or it is defective, worthless, and of no use. Unlike waste, scrap has monetary valuable material, especially recovered metals. Wastes like non-metallic materials are also recovered by separation or recycling



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processes. According to the phrase (WASTE IS NOT THE WASTE), metal waste, especially, became a relatively high value with very minimum cost in many applications. The waste used in this work is the metal residuals materials from mechanical industrial processes such as iron filings, iron turning lathe, and aluminum turning lathe. The metal waste materials may be used as ferrous fibers as replacing steel fibers in fiber reinforced concrete. A sieve analysis based on ASTM C136 was performed on a sample of metal waste. The iron filings took from the product passed from sieve size 1.18 mm while the iron turning lathe and aluminum turning lathe took from the product passed from sieve size 4.75 mm. (Figure 1) shows the machinery waste such as iron filings, iron turning lathe, and aluminum turning lathe that has been used in this work as ferrous materials added to the concrete mix. Different percentages of machine waste added to the total volume are shown in (Table 1).

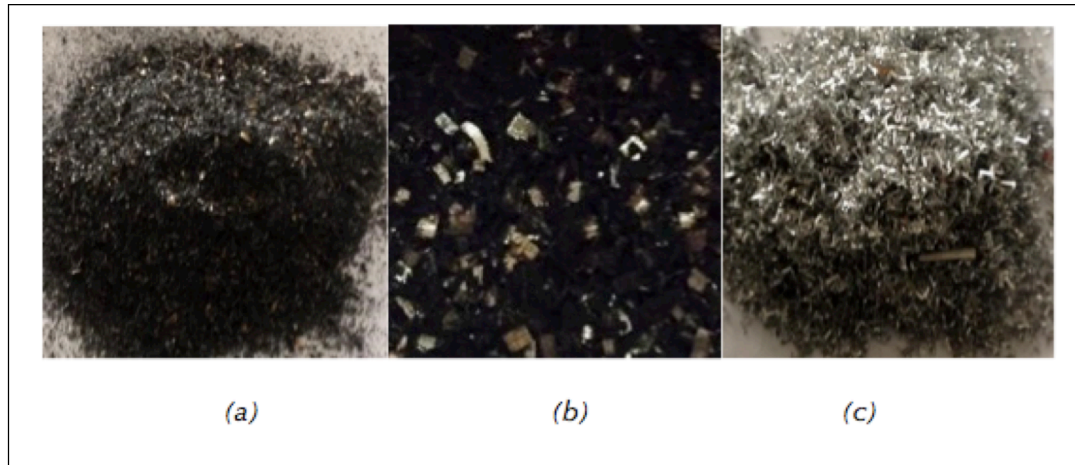


Figure 1. Industrial machines waste (a) iron filings, (b) iron turning lathe, and (c) aluminum turning lathe

Table 1. Metal waste percentages added to concrete mixes

Specimen	Iron filings	Iron turning lathe	Aluminum turning lathe
FER-RS1	-	-	-
FER-RS2	2%	-	-
FER-RS3	-	2%	-
FER-RS4	-	-	2%
FER-RS5	0.5%	0.5%	1%
SCC-RS1	-	-	-
SCC-RS2	2%	-	-
SCC-RS3	-	2%	-
SCC-RS4	-	-	2%
SCC-RS5	0.5%	0.5%	1%



2.2 Reinforcing steel

The ribs of a panel designed with maximum flexural reinforcement and without shear reinforcement. Deformed steel bars (1 bar/rib) were used with a nominal diameter of (16 mm) for the main reinforcement in the tension face. The tensile test of the steel deformed bars was carried out according to standard specifications of the American Society for Testing and Materials (ASTM).

2.3 Water-cement ratio and superplasticizer

A water-cement ratio of (0.4), as well as a dosage of (1.6%) of the cementitious material weight of superplasticizer that is commercially known as "TOPFLOW SP 603", had been used throughout this work. It is preferred to add the superplasticizer after the addition of (60-70) % of the mixing water. It provides the required acceleration of strength gain at early and later ages and compatible with Portland cement that meets the international standards. Plasticized concrete reveals a large increase in a slump without segregation. This provides the enough time after mixing to cast and finish the concrete surface. Ordinary tap water had been used for all concrete mixes.

2.4 Ferro cement

Ferro cement is a composite structural material containing a matrix of cement mortar reinforced with 2D or 3D layers of small diameter wire mesh and uniformly distributed throughout the cross-section. Locally available and most common form involves steel galvanized square mesh with a diameter (0.7mm) and (10 mm) spacing. Normal reinforcing bars, (5mm) in diameter in a skeletal form spacing (50 mm) in both directions were added to the wire meshes to achieve a stiff reinforcing cage. The steel wire meshes tied with skeletal bars to reinforce the flanged section of the one-way panel. The cement mortar paste should be designed for suitable strength and maximum density and impermeability to minimize the voids, with sufficient workability. A cement/sand ratio of (1:2), natural yellow sand passing an ASTM No.8 (2.36 mm) sieve and ordinary Portland cement type (1) were used for Ferro cement ribbed panels.

2.5 Self-compacting concrete

Self-compacting concrete SCC, also known as self-consolidating concrete, provides special properties over the conventional concrete. The main features of SCC are the liquidity nature, the low noise level, fast construction, quality and durability improvement, no vibration needed, the ability of fill the spaces and passes through the reinforcing bars by the own weight (Gensel et al., 2011) and (Parra et al., 2011). Ordinary Portland cement type I, natural sand, and crushed gravel of maximum size (10 mm) were used in the concrete mix. Limestone powder as pozzolanic fillers is usually used to optimize the flow behavior and particle packing of the cementitious paste in SCC mixtures. The size of the limestone powder particles is less than (0.125 mm) (Sieve No. 200), which satisfies the European federation dedicated to specialist construction chemicals and concrete systems recommendations (EFNARC, 2002). The adopted percentage of limestone powder was (10) % of cement weight. The reinforcing steel of the flanged section of the SCC panels was (5 mm) at (50 mm) spacing in two directions as same as the steel in Ferro cement panels.

2.6 Ribbed panel mold

Sheets of galvanized steel plate of (1.7mm) thickness were folded to form a corrugated section of the mold. Two molds were locally manufactured of length (1000 mm) with section dimensions shown in (Figure 2).



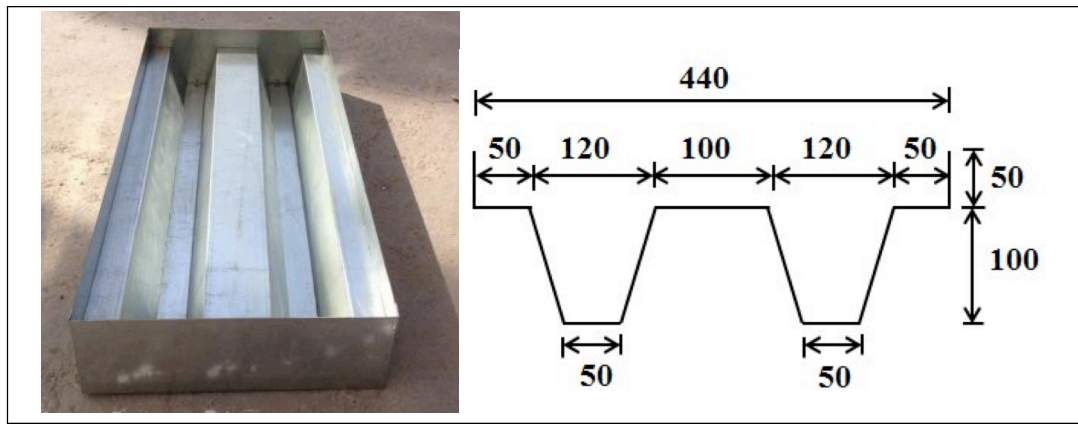


Figure 2. Galvanized ribbed panel mold and section dimensions (All dimensions in mm) Casting

The casting of the ribbed panel is shown in (Figure 3). For SCC, the mix procedures were according to (Al-Jabri, 2005). (Figure 4) shows the overall ribbed panels after casting.



Figure 3. Cast of SCC and FER ribbed panels



Figure 4. Ribbed panels after casting



After completing the required curing period, all panels were tested using a hydraulic testing machine of (3000) kN capacity under monotonic static loads up to the failure load. The panels tested as simply supported slabs with a clear span of (900 mm) under uniformly distributed load. At each load stage of (2 kN), vertical deflection at the mid-span was observed and recorded by dial gauge of (0.01mm) accuracy. At the first crack appeared, the load corresponding was noted and recorded. The loading increments were applied until failure.

3. Results

The experimental results of tests of materials used in this work had been conducted. (Table 2) gives the obtained results of yield strength, ultimate strength, and modulus of elasticity of wire mesh and steel plain bar. Control specimens were taken from each Ferro cement and SCC mixes to obtain their mechanical properties. The results of average strengths for three cubes (50mm), three cylinders (75x150mm) and three prisms (40x40x160mm) for Ferro cement mix and also the results of average strengths for three cubes (150mm), three cylinders (150x300mm) and three prisms (100x100x500mm) for SCC mix are shown in (Table 3).

Table 2. Characteristics of wire mesh and steel bar

Type of steel	Yield strength (MPa)	Ultimate strength (MPa)	Modulus of elasticity (MPa)
Square wire meshes 0.7 mm dia.	315	520	69000
Plain bar 5 mm dia.	510	590	198750
Deform dar 16 mm dia.	610	724	205000

Table 3. Mechanical properties of control specimens

Specimen	Cube compressive strength at 28 days, f_{cu} (MPa)	Cylinder compressive strength at 28 days, $f_{c\phi}$ (MPa)	Modulus of rupture f_r (MPa)
FER-RS1	34.8	30.2	3.72
FER-RS2	43.4	36.7	4.54
FER-RS3	39.5	32.9	4.3
FER-RS4	17.4	14.1	3.1
FER-RS5	21.3	17.7	3.61
SCC-RS1	38.4	33.2	4.2
SCC-RS2	47.5	40.2	4.62
SCC-RS3	42.7	34.8	4.4
SCC-RS4	19.2	15.3	2.9
SCC-RS5	24.6	19.3	3.72

(Figure 5(a)) (Figure 5(b)) shows the effect of the waste on mechanical properties for the FER and SCC panels respectively. The addition of the iron filings powder and iron turning lathe improves the compressive strength and rupture strength while the aluminum turning lathe exhibits an opposite effect. The justification of this improvement may be due to the presence of the well distributed ferrous materials which act as steel fibers that reduce the possibility of the local failure and delay the ultimate cracking loads.



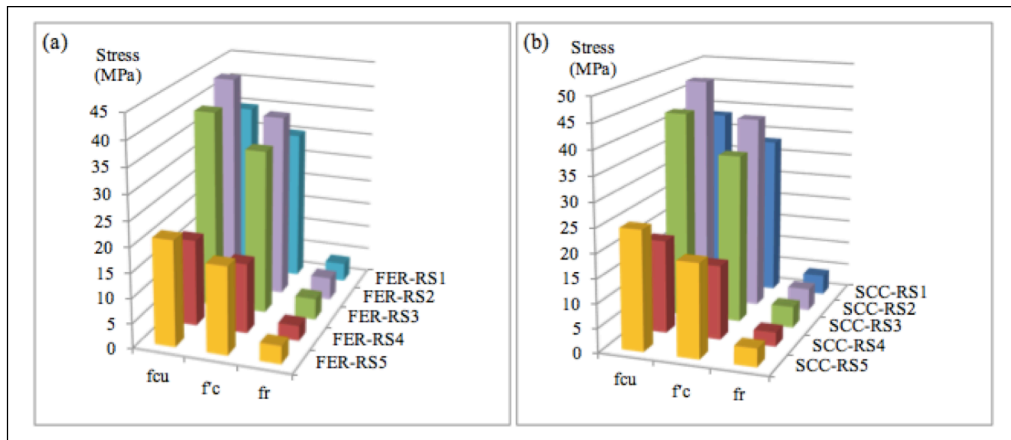


Figure 5. Values of mechanical properties (a) FRE specimens (b) SCC specimens

The results of tested ribbed panels are described in (Table 4) which summarizes the results of the first cracking load P_{cr} and ultimate load P_u for the tested specimens.

Table 4. Cracking and ultimate loads and deflections

Specimen	Cracking load P_{cr} (kN)	Cracking deflection Δ_{cr} (mm)	Ultimate load P_u (kN)	Ultimate deflection Δ_u (mm)	Ductility factor
FER-RS1	20	1.35	52	7.8	5.78
FER-RS2	28	1.13	68	3.27	2.89
FER-RS3	24	0.63	64	2.98	4.73
FER-RS4	14	0.96	34	6.9	7.18
FER-RS5	16	1.61	42	5.02	3.11
SCC-RS1	30	0.88	72	6.25	7.1
SCC-RS2	36	1.05	102	4.4	4.19
SCC-RS3	34	1.44	92	5.75	3.99
SCC-RS4	24	1.45	52	4.39	3.02
SCC-RS5	32	2.5	58	7.5	3

(Figure 6) shows that the iron waste enhances the cracking and ultimate loads. On the other hand, the effect of aluminum waste decreases the values of the cracking and ultimate loads.



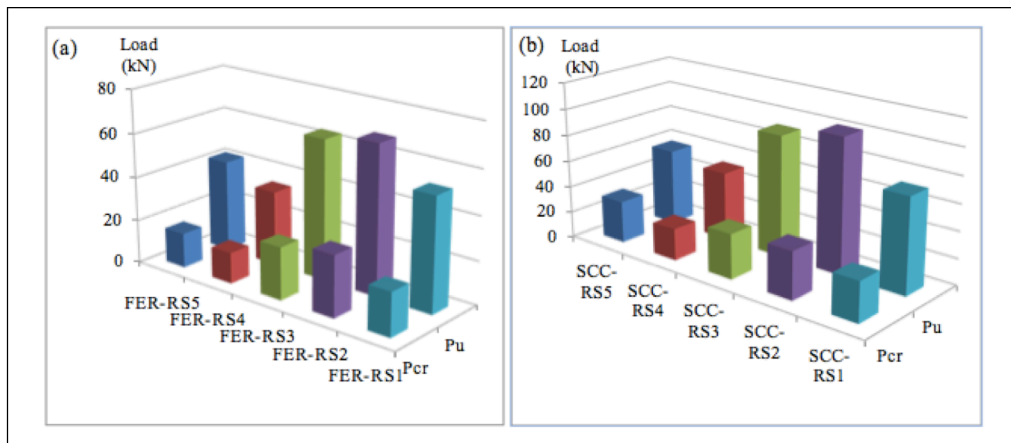


Figure 6. Cracking and ultimate loads for (a) FER panels (b) SCC panels

In general, (Figure 7) shows that the cracking and ultimate deflection decrease with the existence of iron waste, and the opposite effect is shown with the aluminum waste for all ribbed panels.

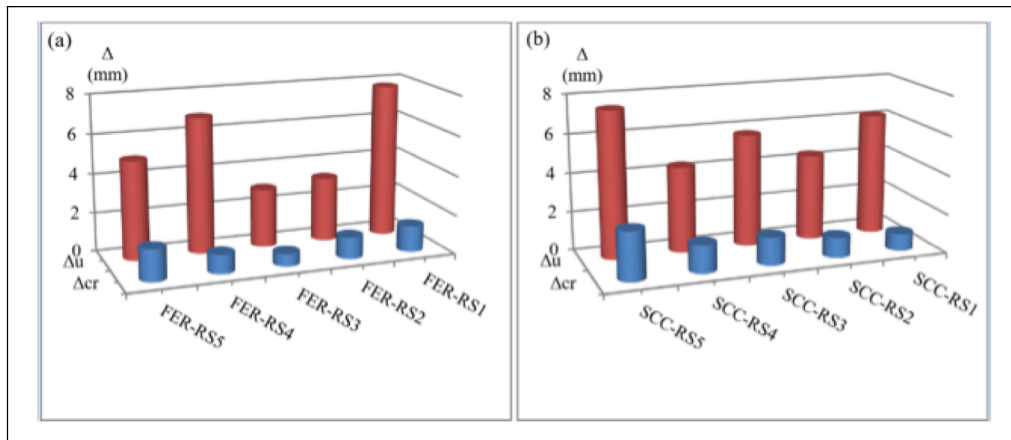


Figure 7. Cracking and ultimate deflection for (a) FER panels (b) SCC panels

(Figure 8) shows the load-deflection comparison for the Ferro cement and SCC ribbed panels respectively. All modes of failure were in the ribs near to the supports as the web shear diagonal cracks as shown in (Figure 9).



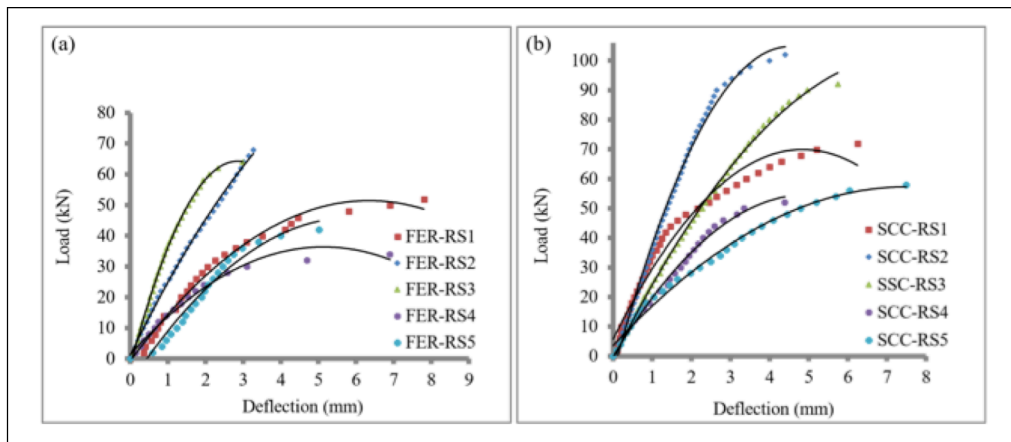


Figure 8. Load-deflection curves of (a) FER panels (b) SCC panels



Figure 9. Web shear crack mode failure in ribs

4. Discussion

The important property of reinforced concrete with metal waste is its superior resistance to crack propagation. The metal wastes possess tensile strength and increased extensibility such as other fibers and they can hold the matrix together even after cracking. Unlike the top and bottom reinforcement, random fiber waste distribution is more effective in terms of absorption of the impact energy and the crack resistance in addition to the ability to control cracks formation (Muda et al., 2016).

The addition of fine materials improves concrete strength providing the workability must be controlled. To maintain workability due to the presence of large amounts of fine particles, high dosages of admixture were required. The increase in amount of steel fibers in the SCC mix enhances the concrete compressive strength with a reduction of the slump flow of the fresh mix (Majain, 2018). It was found that the SCC has the ability to deform its shape quickly under its weight, even when using the fine or coarse metal wastes up to 2%. However, other researchers conclude that the increase in the recycled steel tire fibers content improves the flexural strength but reduces the compressive strength (Hamza et al., 2018).

Splitting tensile, flexural, and compressive strengths of hardened concrete improved by using waste steel fibers in SCC with the increase in the volume fraction of the fibers (Koroglu, 2017). The addition of the recycled steel fibers decreased the slump flow of SCC, and both the content and length of recycled steel fibers affected the compressive and flexural strength of SCC (Younis et al., 2018).

The strength characteristics of the concrete were increased by adding the lathe machine scrap up to (1.5%) by weight, and a slight reduction in the strength properties of normal concrete M20 was noticed after this percentage (Qureshi et al., 2016).

With a partial replacement of fine aggregate by iron waste, (Krikar et al., 2018) found that (12%) of the iron waste was more efficient in both the compressive and flexural strength and the concrete reaches to the maximum strength in shortest time.

(Girskas and Nagrockien, 2016) showed that the replacement of the fine aggregate with the steel cord scrap causes lower absorption of water and higher compressive strength in the adjusted concrete specimens. Also, the porosity parameters have been observed to change in the concrete specimens with steel scrap. The closed porosity has increased and thereby, the freeze-thaw resistance of the modified concrete specimens has improved.

In this study, a significant benefit of using the metal waste with the reinforced concrete ribbed panel as a ferrous fiber appears by increasing the ultimate load and decreasing the central deflection for ribbed panels contained iron filings powder and turning lathe, whereas the opposite effect arises for panels contained aluminum turning lathe with expected improving sound and heat insulation owing to expanding in volume and porosity of the section.

The increase in compressive and flexural strengths with use the iron filings powder may be due to the well distributed of the iron filings powder. The percentage of increase in compression strength of the specimens with iron turning lathe less than the specimens with the iron filings powder because of the difficulty of distributing the fibers in the concrete mix due to irregular shapes compared with the dense concrete mix with iron filings.

The use of the lathe as an iron fiber with a specific shape factor has a side effect due to fiber balling in the concrete mix. Also, the use of the filings as an iron powder with high percentages causes agglomerate the powder particles due to magnetic attraction forces. Adding iron filings powder and turning lathe increases the bond between iron fibers and cement mortar across the cracks and improving the mechanical properties of the hardened state of concrete. The crack propagation resisted by the iron fibers which spread out across the cracks randomly and prevent sudden failure.

All deflection comparisons were computed at the same loading value which represents the deflection values at the lowest ultimate load. The Ferro cement panels with iron filings powder and turning lathe show increasing in the ultimate load by 31% and 23% and decreasing in the central deflection by 58% and 62% respectively, while the Ferro cement panels with aluminum turning lathe show decreasing in the ultimate load by 35% and decreasing in the central deflection by 12%.

The SCC panels with iron filings powder and turning lathe show increase in the ultimate load by 42% and 28% and decreasing in the central deflection by 30% and 8% respectively, while the SCC panels with aluminum turning lathe show decreasing in the ultimate load by 28% and decreasing in the central deflection by 29%. The ultimate load of SCC panels was higher than the ultimate load of Ferro cement panels. The presence of coarse aggregates and the high workability in SCC may reduce the balling and agglomeration of the lathe and filings wastes in the concrete mix and contribute to the improvement of structural behavior by a relatively uniform distribution of the waste.

5. Conclusions

The use of iron waste with reinforced concrete mixes improves the structural behavior by increasing the ultimate load capacity and decreasing the ultimate deflection except the specimens contained aluminum waste that show the opposite behavior.

All tested FER and SCC ribbed panels failed by shear stress. The shear failure took place by diagonal splitting in the ribs near to the supports as web shear diagonal cracks.

The existence of aluminum waste in concrete mixes plays a dominant role of the reduction in the ultimate load even with the presence of other iron waste.

The effect of adding iron waste improves concrete tensile strength and ductility.

It is useful and appropriate to replace costly steel fibers by types of iron waste.

The behavior of SCC ribbed panels shows a higher ultimate load than the Ferro cement ribbed panels.

The well distributed and the shape function of the waste plays an important role to enhance the concrete strengths.

The corrosion problem must be considered by treating the concrete surface with protective coatings.

6. Acknowledgments

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