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Sustainable Incorporation of Waste Strapping Plastic Belts as Additional Flexural Reinforcement in Concrete Beams

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ABSTRCT

This study aims to examine the flexural behavior of reinforced concrete (RC) beams containing waste strapping plastic belts as additional flexural reinforcement. Five beams specimens were prepared and tested until failure under the effect of flexural loading. First beam specimen is the control one without waste strapping plastic belts. The other four beams have the same reinforcement details as in reference one in addition to presence of waste strapping plastic belts as additional flexural reinforcement. The additional reinforcement are 2, 4, 8 and 12 strips . Load of first visible crack, ultimate load and midspan deflection were recorded for each tested beam. Percentage of ultimate load increasing for each beam was computed. Observations on general behavior, failure mechanisms and mode of failure were recorded. The experimental results refer to increase of flexural load carrying capacity in presence of plastic strips as additional flexural reinforcement. The maximum percentage was (34.7 %) for beam with (12) strips as compared with control beam .

استخدام مستدام لمخلفات أحزمة الربط البلاستيكية كتسليح انثناء إضافي في الاعتاب الخرسانية

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الكلمات المفتاحية:
احزمة التعبئة البلاستيكية
سلوك الانحناء
استخدام صديق للبيئة
جسور خرسانية مسلحة
مواد النفايات
شراء بلاستيكية

الملخص

يهدف هذا البحث الى دراسة أداء الانثناء للأعتاب الخرسانية المسلحة الحاوية على مخلفات احزمة الربط البلاستيكية كتسليح إضافي للانثناء . الدراسة تضمنت صب خمسة نماذج أعتاب و فحصها لحد الفشل تحت تاثير تحميل الانثناء . النموذج الأول المرجعي ذو التسليح التقليدي بدون مخلفات احزمة الربط البلاستيكية . والاعتاب الأربعة المتبقية تمت إضافة تسليح بمخلفات احزمة الربط البلاستيكية كتسليح إضافي الى التسليح التقليدي . التسليح الإضافي للأعتاب كان 2 و 4 و 8 و 12 حزام . تم تسجيل الحمل عند الشق الأول , الحمل الأقصى و الانحراف في منتصف الفضاء لكل نموذج . تم ايضا تسجيل الملاحظات المتعلقة بالتصرف العام للنماذج وآلية الفشل ونمطه. كذلك تم حساب الزيادة في الحمل الأقصى لكل نموذج . اشارت النتائج العملية الى ان تحمل الانثناء للنماذج ازداد بزيادة احزمة الربط البلاستيكية كتسليح إضافي . و كانت افضل نسبة زيادة هي(34.7 %) لنموذج العتب الذي يحتوي على 12 شريحة بلاستيكية مقارنة مع النموذج المرجعي بدون شرائح .

1. Introduction

The major objective of waste recycling is to diminish the amount of waste with the intention of reductions their ecological influences. Additionally, the waste recycling offers a source of additional materials that convention natural materials reduction rate. Consumption of waste constituents in the application of civil engineering as additional reinforcement materials one of the promising methods of recycling materials [1–5].

Many researchers studied the flexular behaviour of concrete beams containing plastic waste materials, concentrating on how these plastic waste materials influence on strength , deflection, and ductility of RC beams, Abdulridha, et. al. [6] , investigated the flexural behvior of RC beams containg differante plastic waste rope as fibers. Four RC beams were prepared from concrete mixes containing different fractions of waste plastic rop fibers ranged from 0 % to 1%. The main findings of the study , the combined of the plastic waste rope as fibers significantly improve ductility and crack behavior of RC beams, regardless the load capacity of RC beams slightly increased. Khatab et. al. [7] , inspected an experimental study to assess the opportunity

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of using waste strapping plastic belts as fibers. Waste strapping plastic belts were shredded into fibers with aspict ratio ranged from 2.5 to 3, then incorporated in concrete mixes with percent ranged from 0 % to 0.5%. Fresh and hardened properties of concrete containing shredded waste strapping plastic belts were examind. The results of study indicated that the workability and compressive strength of modfided mixes decrease as percent of plastic fibers increased , on contrary the spiltting strength increased as fibers precents increased . Smailar trend was stated by other studies [8–10].

Khan and Ayub [11] , used plastic strips prepared from polyethylene terephthalate bottels as additional flexular reinforcement in selfcompacting RC beams. The polyethylene terephthalate bottels ware shredded as strips with width 10 mm, and then incorporated in RC beams. The outcomes of the study revealed that combind the polyethylene terephthalate bottels as additional flexular reinforcement in selfcompacting RC beams considerably improve the flexular behavior. The improvmant percentage in the behavior reached to 13 %. Abdullah et. al. [12], utilized waste strapping plastic belts as replacement of steel flexular reinforcement. Ten RC beams were prepared with different flexular reinforcement. The main steel reinforcement of RC beams were replaced by waste strapping plastic belts , the adapted plasic reinforcement are 3 , 6 , and 9 strips. The authors discovered that the ultimate load capacity of the RC beams substantially decrease when the traditional steel reinforcement replaced by plastic strips. The reduction precntage of ultimate load capacity for all beams more than 50 % when compard with control beams without plastic strips. Jouyandeh et.al. [13] , conducted experimental study on flexular behaviour of RC beams containing polyethylene terephthalate woven bars as longitudinal steel replacement. First , the woven plastic bars were prepared from polyethylene terephthalate plastic bottles. Then , the woven plastic bars incorporated in RC beams and partially and totally replecmant of bottm steel reinforcement. The outcomes of the research revealed that the load capacity of RC beams noticeably declined as replaced plastic woven bars increased. The reduction percentage are about 29 % , 53 % , and 89% for one , two, and three replaced plastic bars respectively. on contrary the ductility ratio increased as woven replaced plastic bars increased. Ali et. al. [14], explored the flexural behavior of the concrete prsims strengthened with strapping plastic belts in tension zone. The strapping plastic belts combined with concrete prisms internally and externally with different areas. The authors stated that the flexural strength increased as the plastic areas increased. Furthermore , the exeternal merge give higher increment than internal for equivalent strapping plastic strips area.

The employing of waste materials in civil engineering applications contributes reducing environment pollution.The present study main objective is to use the waste strapping plastic belts (WSPB) strips as additional flexural reinforcement. The WSPB strips without treatment were merged into RC beams in the lower section for beams (tenstion zone). The adapted additional plastic flexural reinforcement ranged 2 to 12 strips.

2. Experimental work

The experimental part of this work, which was carried out on a beam specimens of reinforced concrete, with and without WSPB strips, subjected to flexural load, includes recording the visible cracking load, final load, and deflection at the midspan. Also, the results of concrete beams that contain WSPB strips are compared with the reference beam that was poured without adding WSPB strips.

2.1. Experimental Program

The Experimental programs were directed to prepare five rectangular beam specimens of reinforced concrete. Details of dimensions and reinforcement are shown in Figure 1. The process included casting, curing and testing. The program also includes many control tests such as cubs, cylinders and prisms that have been conducted, which are necessary for the properties of concrete after hardening (hardened concrete compressive and tensile strength). During the test, the dimensions of the specimen, their temperature, the longitudinal and transverse reinforcing steel, and the loading application protocol remain the same. The fracture load, the final load, the failure mode, the behavior of the specimen before failure, and the cracking pattern were recorded to be presented and discussed.

2.2. Materials

Ordinary Portland cement (Type I) was used in the current study.The physical and chemical characteristics exhibited that the cement fit in to the requests of ASTM C-150 [15]. Fine aggregate used in specimens making was of naturally formed type, The size distribution of utilized sand conform with ASTM C-33 [16]. Coarse Aggregate (Gravel) was used in a gradation (5-19) mm size. Also it is of naturally formed type. The size distribution of utilized gravel conform with ASTM C-33 [16]. Chemical Admixture, super plasticizer for concrete was employed in this study. It was adapted to ASTM C494 [17]. Tap water was used in all concrete mixing and curing. Reinforcing steel with a diameter of 8 mm was used in the longitudinal direction for the tensile region and 6 mm in the longitudinal direction for the compression region. Reinforcement steel was used for the transverse direction with a diameter of 10 mm and a number of 12 for each beam. All Reinforcing steel bars were of grade 60 deformed type. It was conformed to ASTM A 1064 [18]. Four reinforced concrete beams were casted with WSPB strips. WSPB strips have a thickness of 1 mm and a width of 16 mm, in the longitudinal direction, with different proportions relative to the reinforcing steel in the tensile area. Specimen B2-2ST contained 2 WSPB strips in one layer, while beam B3-4ST contained 4 WSPB strips in two layers, and beam B4-8ST contains 8 WSPB strips in four layers (2 WSPB strips for each layer). As for beam B5-12ST, it contained six layers (2 WSPB strips for each layer) as shown in the Table (1) and Figures (1,2, and 3) .

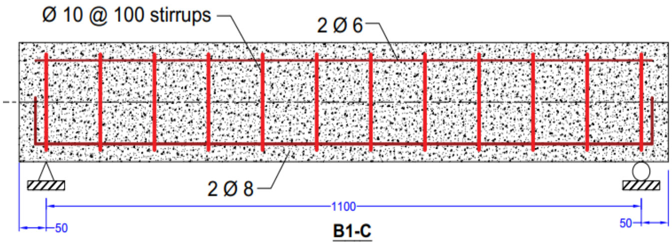
2.3. Mix Proportion

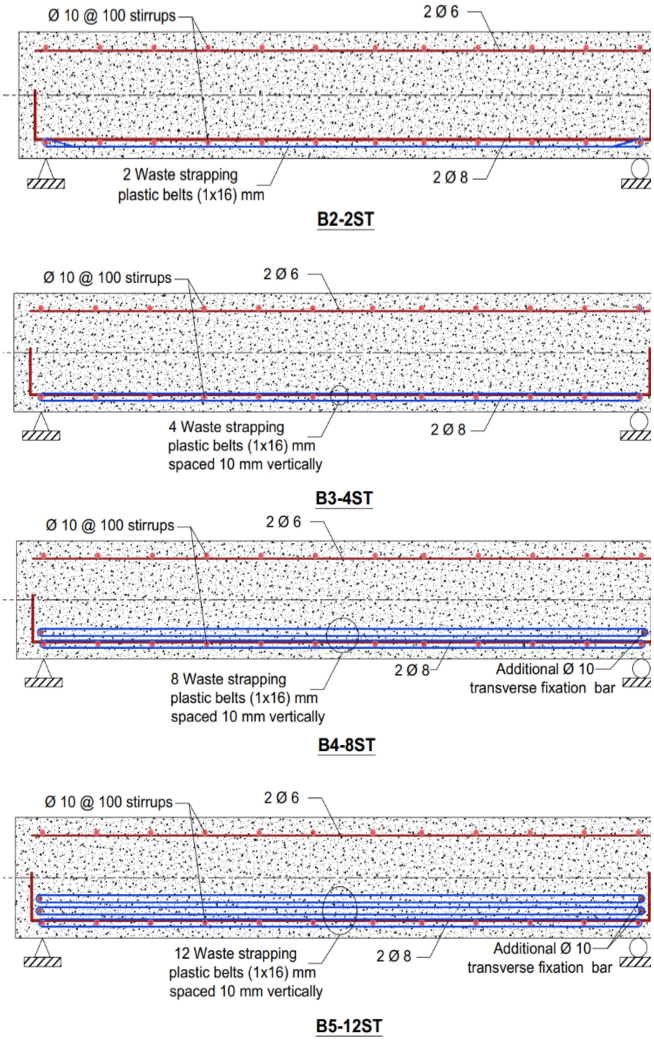
Depending on the previously stated requirements, the following mix proportions were used to obtain the required properties for the concrete used in current study, based on previous studies [19][20] . As showen in Table (2).

Table (1): Specimens details.

Beams	A_s* mm^2	No. of strips layers	No. of strips	WSPB strips Dimensions mm	A_p** mm^2	$\frac{A_p}{A_s}$ %	$A_s + A_p$ mm^2
B1-C	100.53	-	-	-	-	-	100.53
B2-2ST	100.53	1	2	1×16	32	32	132.53
B3-4ST	100.53	2	4	1×16	64	64	164.53
B4-8ST	100.53	4	8	1×16	128	128	228.53
B5-12ST	100.53	6	12	1×16	192	192	292.53

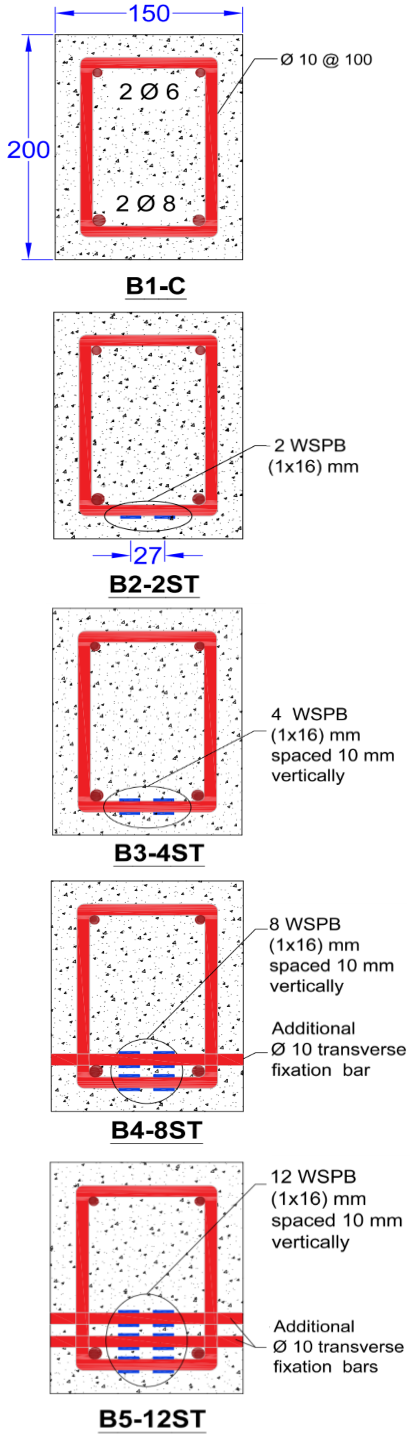
* Flexural steel area (bottom reinforcement). ** Area of added waste plastic strips (bottom).





(a) Longitudinal Sections.

Figure (1): Beams Details.
(a) Longitudinal Sections.
(b) Trnsverse Sections
(Note: All dienssions are in millimeters)



(b) Transverse Sections.

Figure (1): (Con'd) Beams details.
(Note: All dienssions are in millimeters)

Table (2): Mix proportions (kg /m^3).

Cement	Sand	Gravel	Water	Plastizer	W/ C
360	940	1050	130	3	0.36

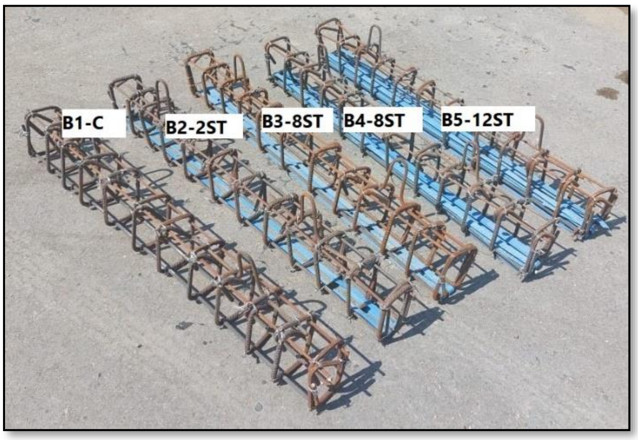


Figure (2): Steel reinforcement with additional plastic strips.

Figure (3): Casting works.

2.4. Control Tests of Normal Concrete

According to the standards, there are many different tests to ensure that the concrete produced is of the normal concrete. It is not necessary to conduct all these tests. Therefore, only two tests were approved for the current investigation, compressive and tensile strengths. Compressive strength (f_{cu}) of normal concrete (NC) was determined using three cubes of (150) mm as average according to (BS EN 12390-3:2019) . All cubes were tested until crashed using hydraulic testing machine. Three (150 x 200) mm cylinders prepared and tested depending on (ASTM Designation C 39-01) were averaged to find the compressive strength (f_c') of NC using hydraulic testing machine. Cylinder compressive strength was needed in present work since the structural design was achieved according to ACI-318 Code which adopts cylindrical samples. Although there is a known relation between the cylinder strength and cube strength for normal concrete samples as ($f_c' = 0.82\ f_{cu}$). Results of the tests are recorded in Table (3) . Modulus of Rupture (f_r) test is employed to find rapture modulus (strength in flexure) of normal concrete by prism sample(s). Modulus of rupture of normal concrete of the present work was found by test result averaging of three standard prism samples. All prisms were of (500x100x100) mm dimensions and tested in accordance with ASTM C78-02 under three point load effect.

Table (3): Compressive and tensile Strengths of NC.

Test	Age (Day)	Test Result (MPa)	
Cylinder Compressive Strength (*f_c'*)		30.2	
Cube Compressive Strength (*f_{cu}*)	28	35.2	
Modulus of Rupture (f_r)		ASTM C78-02 3.625	ACI 318-14 2.806

2.5. Instrumentation and Test Measurements of RC beams

All specimens were tested until failure due to flexure. Four point loads test setup was used for all specimens , as adapted in previous studies [21–23] . Figures (4 and 5) show the adopted test setup. Specimen under test is loaded gradually so the flexural failure occurs finally. The amount of deflection was measured at the midspan of the specimens because it represents the amount of the greatest deflection that occurs during the process of load application.

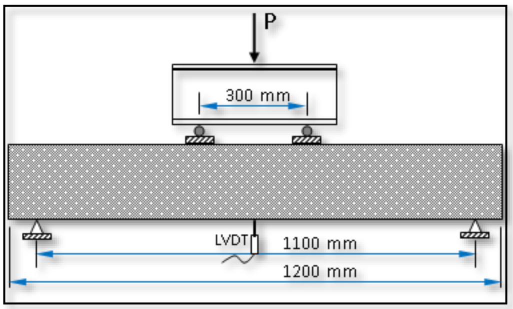


Figure (4): Specimens test setup.

Figure (5): RC Beams under static test.

3. Results and Discussion

The aim of this study, as mentioned previously, is to investigate the effect of presence of WSPB strips as additional reinforcement on the flexural behavior of simply supported beam. The objective of the study is planned to be achieved by preparation and testing of five specimens as described. All specimens were tested under effect of four-point loads setup until failure due to flexure. General behavior, failure mode and crack pattern were studied. During the test of each specimens, the recorded data include first visible crack load, ultimate load and corresponding deflections. Also, data of increasing of deflection with loading was recorded; so load-deflection curves can be constructed. Discussion of all experimental test results comparisons of test results with respect to control specimens were introduced. The same would be applied to behavior observation of tested beams.

3.1. Beam Specimens' Behavior

Behavior of simply supported beam during test under effect of 4-point loads may be generally described. The failure was occurred due to flexure. At early loading steps the beam under test behaves elastically. Therefore deflection and the flexural cracks did not appear. This means that the tension stress was less than the tensile strength of concrete and the cross-section was able to understand the applied load.

As load was increased one or more cracks appeared at or near the midspan. This means that the developed tensile stress overcome the tensile strength in fact. The concrete section at initial stage of loading resists all the applied load. Thereafter, Concrete, flexural reinforcement and transverse reinforcement will resist the applied load together. At same time the midspan deflection and the cracks width have small values at the beginning of the test and increased gradually until reaching their maximum values at failure. The visible first crack loads as well as the ultimate deflection and ultimate load capacity were recorded.

3.2. Failure Mechanism

The cracks are spreading across the depth of beam cross section gave good notice for the mechanism of failure. First visible crack occurred at bottom fiber located at or near the midspan in all specimens. As loading was increased, new cracks begin to appear at other locations and the old ones come to be wider. All cracks propogate from bottom tensile fiber towards compression top fiber. Accordingly, the final failure position of all beams occurs at mid span region between the two applied point loads. Generally, the presence of additional plastic strips leads to slight decrease in crack width.

3.3. Cracking and Ultimate Loads

Throughout the test, both cracking and ultimate loads were recorded. The percentages of flexural load capacity increasing are calculated to be as shown in the Table (4). Nearly, the cracking loads have same values because only the concrete resists the applied loads until its rapture strength is reached. Thereafter concrete, steel reinforcement and added WSPB strips all together resist the applied load. The ultimate load is increased as number of WSPB strips is increased. Beam specimens, B2-2ST, B3-4ST, B4-8ST, and B5-12ST achieve an increments of 14.5 %, 25.3 %, 32.8 % and 34.7 %, respectively as compared to control one, B1-C. As compared with B4-8ST, the uultimmate load capacity incesing of B5-12ST (5.7 %) is too small despite of presence of larger ammount of WSPB strips, this trend somewhat similar to previous studies [24,25]. It can be said tht the rate of increasing percentage is decreased with increasing of WSPBs. This may be resulting from adding the WSPB strips in form of layers because of limitation of section width. As number of laers is icreaased, the centrid of WSPB strips go up towards the neutral axis decreasing of section lever arm value. Consequently the section moment capacity is decreased.

Table (4): Cracking, ultimate loading and percentage of change.

specimen	P_{cr} (kN)	P_u (kN)	% of change P_{cr}	% of change P_u	Δ (mm) at P_{cr}	Δ (mm) at P_u	Ductility index
B1-C	20	46.3	-	-	1.42	12.50	8.8
B2-2ST	18	54.0	-10	14.5	1.23	11.90	9.6
B3-4ST	20	58.0	0.0	25.3	1.30	13.17	10.5
B4-8ST	22	61.5	-10	32.8	1.28	12.50	10.0
B5-12ST	20	62.4	0.0	34.7	1.15	13.28	11.5

3.4. Load – Deflection Relation

During the test of each beam, the load was increasing gradually. The midspan deflections were recorded with increasing of the applied load. The relation between the deflection and the applied load was drawn for each beam. Figure (6) shows this relations for tested specimens. Examimning the load-deflectin curves, it can be seen that the presence of WSPB strips makes the beam stiffer. This lead to increase the section moment capacity causing final deflectins to be larger.

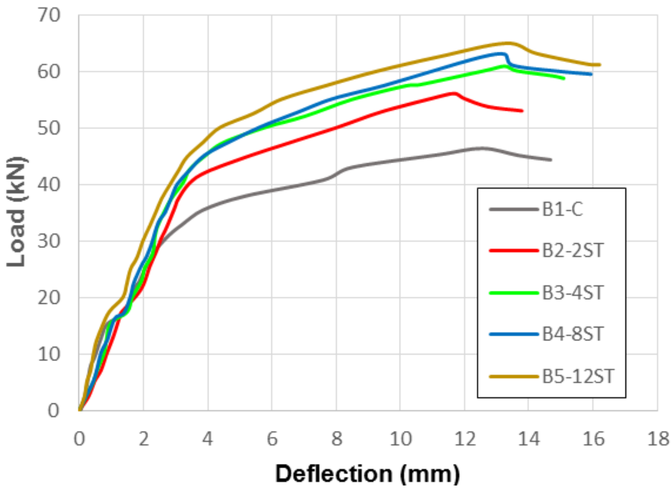


Figure (6): Load-Deflection Relations for tested specimens.

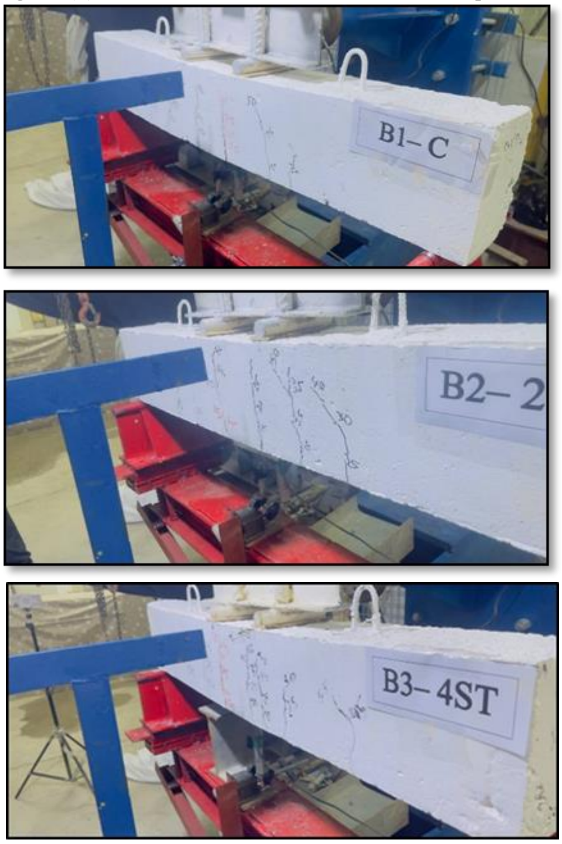


Figure (7): Mode of Failure for tested RC beams.

3.5. Mode of Failure

All beams were tested to failure under flexural loading effect. First beam (B1-C), second beam (B2-2ST) and third beam (B3-4ST) failed due to increasing of tensile stresses which exceed the flexural tensile strength at the bottom. Fourth beam (B4-8ST) seems to have combined failure mode due to tensile stress increasing at bottom as well as incresingg of compressive stress at top. Fifth beam (B5-12 ST) seems to be filled by increasing of compressive stresses at top, which mean they have primary compression filler. Therefore, it may concluded that the last beam (B5-12ST) may have further tensile strength due to presence of larger number of WSPB strips.as showen in Figure (7).

4. Ductility

Ductility is one of immprtent properties for the structure's performance. Higher ductility of a structures is better ablity to encounter different pssible load conditions than that of lower ductility. Reinforced concrete members are designed to be under-reinforced to achieve amount of ductility required to ensure secondry compression failure [22]. In present study, the ductility index is depended to evaluate the ductility of tested beams. The ductility index is obtained thrugh dividing of ultimate displacement on yield displacement. The ductility indeces are displayed in Table 4. Examining the ductility index values, it can be concluded that the ductility increases slightly with increasing of number of WSPB strips in the sectin. Beam specimens, B2-2ST, B3-4ST, B4-8ST and B5-12ST have an increments of 9.1 %, 19.3 %, 13.6 % and 30.6 %, respectively when compared with control one, B1-C. Generally, precence of WSPB strips as additionl flexurl reinforcement enhances the flexural behavior and makes tested beam specimens to have more ductility through cntrolling cracks width and restricts their propogatin across section depth , this tendency slightly similar to earlier studies [25,26].

5. Conclusions

Depending on the results obtained out from the present study, the following main conclusions can by drawn :

1- Observable increasing in flexural load carrying capacity can be achieved by adding waste strapping plastic belts strips as additional flexural reinforcements .
2- Maximum percentage of increasing in flexural load carrying is (34.7%) which is regarded to beam with 12 waste strapping plastic belts strips.
3- Generally, midspan deflection is increased with increasing of WSPB strips amount in the section due to increasing of section moment resisting capaacity.
4- Cracks seem to be smaller with increasing of waste strapping plastic belts strips number in RC beams.
5- Beam designated (B5-12ST) failed due to increasing of compressive stresses which exceeded the compressive strength of beam concrete, so it may have further load capacity at tensile zone.
6- Ductility is increased for beams having waste strapping plastic belts strips.

6. Recommendations

1- Another types of waste plastic strips can be used for future work.
2- The methodology of present study may be applied for other types of concrete like light weight concrete (LWC) and self-compacting concrete (SSC).
3- The same idea of this work may be performed to other types of loading such as shear and torsion.

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