Applying Reused Steel Bars to New Constructions (A Case Study in Gaza Strip)

Bassam A. Tayeh[1,a*] Mohammed W. Hasaniyah[1,b]
Mohammed Ziad Abu Anza[1,c] Mohammed A. Abed[2,d]

[1]Civil Engineering Department, Faculty of Engineering, Islamic University of Gaza, Gaza, Palestine
[2]Budapest University of Technology and Economics, Müegyetem rkp. 3, Budapest 1111, Hungary
[a] btayeh@iugaza.edu.ps [b] mhasaniyah@gmail.com [c] mohemm34@gmail.com
[d] mohammed.a.m.abed@hotmail.com

***Corresponding author**: Bassam A. Tayeh , Civil Engineering Department, Islamic University of Gaza, Gaza, Palestine, Tel: + 972-82644400; Fax: + 972-82644800 , E-mail: btayeh@iugaza.edu.ps

Abstract—Demands for construction materials and for steel in particular are globally increasing. In 2008, the construction sector consumed 56% of the total 1088 million tons of steel demand. Steel production is a major contributor to greenhouse emissions with an estimated 25% of total CO_2 emissions. Therefore, reusing and recycling steel could be beneficial in lowering the global levels of CO_2 emissions. This paper examines the possibility of using steel form the debris of damaged buildings during the 2014 war on Gaza, Palestine. The lack of steel bars and their uprising prices in Gaza strip encouraged the trend of using used steel in new constructions. The paper examines the properties of used steel in comparison with the standards. It also compares between steel of known and unknown extraction sources and between steel extracted under an expert supervision and steel extracted by local residents. The validity of reused steel is examined through a process of Re-certification. The process includes applying a tensile and bend and re-bend test to used steel bars. The results indicate that some reused steel bars meet the specification for new constructions. The results also show that steel bars extracted under a specialist supervision shows better performance than those extracted by local steel collectors in Gaza.

Index Terms: CO_2 emissions, Bend & Re-bend test, Destroyed buildings, Gaza Strip, Reused steel bars, Tensile test.

I INTRODUCTION

Steel is the most widely used engineering material around the world; the global demands for steel in 2008 was estimated at 1088 million tons. The construction sector consumed approximately 56% of global steel demands. These were divided into 358 million tons in buildings and 238 million tons in infrastructure projects [1]. Steel production is one of the major causes for greenhouse gas emissions. The global industrial carbon emissions are around 10000 million tons CO_2; steel industry approximately produces 25% of these emissions [2]. Therefore, research attempts for recycling or reusing steel might have beneficial effects on reducing CO_2 emissions. In a research carried in the Netherlands, the United Kingdom, and Sweden, it was found that at the end of a facility life, 83% of steel are recycled, 14% are reused and 3% are landfilled [3]. Although several steel sections are reused, steel bars from reinforced concrete buildings are never reused globally [4]. It was also found that reusing a particular amount of steel for one time can reduce CO_2 emissions by 35% in comparison of using newly-fabricated-steel members. Recycling these used members for one more time can decrease CO_2 emissions by 45% in comparison with using new members. These numbers reflect the importance of recycling and reusing steel instead of fabricating new steel members. They also show that there is a barrier for steel reusing and that industry prefers steel recycling [5, 6]. Reusing steel members offers greater environmental advantages than recycling since there is no (or few) environmental impacts associated with reprocessing. For example, reusing a steel beam in its existing form is more efficient energy and cost wise than re-melting the beam and fabricating a new member out of it.

Over 500 million tons of steel are recovered and recycled annually worldwide. The United Kingdom construction industry consumes around 420 million tons of materials annually and generates some 90 million tons of construction, demolition and excavation waste, of which 25 million tons end up in landfills [7].

The economic value of reusing steel can be strongly linked to the cost of new steel [8]. Reusing steel is advantageous in construction from both economic and environmental perspectives. However, there are some barriers that limit the applications of reused steel in new constructions. These barriers are summarized in the following points:

1. **Sourcing Steel:** Reusing steel members in new constructions requires that the extracted members from old constructions meet the design requirements of the new construction. This requires the design team to investigate the reuse supply early in the design process to attempt to secure appropriate sections [6]. There is usually a limited supply of reused steel that fits the new design, which results in a mixture of reused and new steel. Sourcing steel requires an intensive work from the structural design team leading to an increase construction cost. The sourcing process generally requires a longer project preparation program to ensure the steel is sourced, tested, re-fabricated (where required) and delivered to site ready for construction. Sourcing of steel can be a challenge since construction is usually faster than demolition which limits the supply of reused steel [6, 9].
2. **Cost implications for structural steel reuse:** There are no inclusive data about the costs of reusing steel due to inexperience of reusing steel worldwide. However, it must contain the costs of deconstruction, shot-blasting, labor work, Reconditon/Certification and fabrication with reclaimed steel. Additional costs of reused steel could emerge from delays in the construction process. These delays could be prevented if using reused steel is planned for at an early stage [2, 6, 10].
3. **Steel Re-certification:** If steel is to be reused, a specialist must take responsibility for certifying its suitability. A visual inspection is firstly required to identify distortion, deflection and significant corrosion segments of the member to be reused. If the steel grade is unknown, either the lowest grade could be assumed, and the structure is designed accordingly, or a tensile test can be conducted to determine the steel grade [4, 6].
4. **Lack of client demand or negative client perceptions:** Clients of new constructions prefer new steel members over reused steel. This results in a lower demand rates for reused steel [2, 10].

CASE STUDY

Gaza strip is one of the most crowded areas in the world, where about 2 million inhabitants live in approximately 365 km^2 [11, 12]. During the past decade, the strip suffered the consequences of consecutive wars which destroyed plenty of buildings and infrastructure either wholly or partially. The prices of steel in Gaza have increased as a result of continuously increasing demand and limited supply. The amount of construction waste from the destroyed houses after the war of 2014 is estimated at about 2.5-3.0 million tons; 22% of this amount is made of steel bars [4, 13, 14] (Fig. 1). The 2008 war left approximately 1 million tons of construction wastes [12]. The strip requires huge amounts of construction materials for buildings rehabilitation and natural growth requirements. In October, 2016, Gaza strip requirements for construction materials were estimated at about 31 million tons [15].

According to the United Nations Office for Projects Services (UNOPS), the allocated quantities of construction materials on their system, Gaza Reconstruction Mechanism (GRM), are 1,046,005 tons cement, 3,904,891 tones aggregates, and 185,161 tons steel bars with a total of 5,136,057 tons [15].

The demand for steel bars in 2014 was 1,049,079.75 tons. However, only 113,702 tons of steel bars were allowed into Gaza Strip between 2014 and 2016. This has left a deficit of 935,377.75 tons in steel supply [15].

This study attempts to validate the reuse of steel bars from destroyed constructions in new buildings. This approach might help in lowering the strip needs for new steel bars.

Fig.1 Steel bars collection

The sources of reused steel bars are destroyed buildings due to bombing or demolishing.

This paper examines the possibility of using steel form the debris of damaged buildings during the wars on Gaza. The paper examines the properties of used steel in comparison with the standards. It also compares between steel of known and unknown extraction sources and between steel extracted under an expert supervision and steel extracted by local residents.

II Methodology

This study aims to confirm the performance and quality assurance requirements for reused steel bars [16] by examining one of the steel reusing barriers, Steel Re-certification. The grade and performance of reused steel are determined and compared with the standards of new steel bars. Thereby, the behavior and suitability of reused steel bars can be determined.

The samples of steel bars are collected and categorized according to their extraction source and whether the bars were sampled under a specialist supervision or not. 27 steel bar samples of various diameters are collected. The three different categories of samples are illustrated in table (1).

Table 1: Categories of steel bar samples according to extraction source and the availability of a specialist

Sample No.	Extraction Source	Specialist Supervision During Extraction	Notes
1	Unknown extraction place	No	The samples are collected from local shops in Gaza that sells reused steel.
2	Known extraction place	No	-
3	Known extraction place	Yes	-

The samples of known extraction sources are compared with those of unknown extraction sources. The samples extracted under the supervision of a construction engineer are compared with those extracted by local residents. This methodology is followed to check whether the extraction place and the specialist supervision affect the performance and quality of reused steel or not.

Steel Re-certification is applied to all samples by firstly visually inspecting steel bars to determine if there any distortions, deflections or significant corrosions in the steel bar. Then, to determine the performance of steel bars, two tests are conducted:

1. Steel Tensile Test: This test is conducted to determine the steel grade. The tensile test is performed according to (ASTM A370) standard to determine the yield stress (N/mm^2), the ultimate stress (N/mm^2), the elongation percentage, and the F_u/F_y ratio for each steel bar [17] (Fig. 2).

Fig. 2 Tensile test of steel bars

2. Bend and Re-Bend Test: This test is executed according to (ASTM A370) standard to determine if there are any cracks in the steel bars [17] (Fig. 3).

Fig. 3 Bend and re-bend test

The tested reused steel bars are then compared with the specifications of the (PS 52-1997) standard [18].

III Results

Table (2) represents the results of the tensile test for the 27 steel bar samples of unknown extraction source. The results indicate that 40.7% of all samples failed at least one limitation standard test (Fig. 4).

Out of six Φ14 bars, five have failed to reach the minimum yield stress point. One out of four Φ18 bars has failed to reach the minimum as well. All Φ10 and two out of seven Φ16 bars have exceeded the maximum yield stress of 520 N/mm^2. Table (2) also shows that three Φ14 bars have failed to reach the minimum ultimate strength of 500 N/mm^2.

Fig. 4 Samples after tensile test

Table (3) shows the results of the tensile test for 33 steel bar samples that are collected form known sources under a specialist supervision. The table reveals that 60.6% of samples have failed at least one limitation of the tensile standard test. Some steel bar samples do not have yield stress point which indicates that the bar has reached its yield limit before testing in the extraction site. Table (3) also shows that 18 steel bars failed to reach the minimum elongation percentage. The ground beam steel bars, which were extracted under supervision, have met all the requirements of the tensile test.

Table 2: Tensile test results of samples from unknown source (shaded cells indicate a failure of sample)

Bar No.	Specified Size (mm)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation %	Fu/Fy Ratio
		400-520	min 500	min 12 %	min 1.25
1	8	478.5	657.9	20.5	1.38
2	8	478.5	657.9	21	1.38
3	8	477.5	676.5	20.5	1.42
4	10	534.7	702.2	15.7	1.31
5	10	536.7	704.2	12.5	1.31
6	10	530	670	13.5	1.26
7	12	484.9	657.1	17.6	1.36
8	12	420	530	12.5	1.26
9	12	450	567	12.6	1.26
10	14	423	584	14	1.38
11	14	419.5	542	13.2	1.29
12	14	395	658	12	1.66
13	14	311.4	543.3	16	1.74
14	14	251.8	377.7	17.5	1.5
15	14	185.5	497	17.5	2.68
16	14	231.9	463.8	17	2
17	16	463.8	589	12.9	1.27
18	16	474	730.6216	14.9	1.54
19	16	474	739.2	16.9	1.56
20	16	547.9	740.7	17	1.35
21	16	522.5	700.1	16	1.34
22	16	507.3	700.1	16.5	1.38
23	16	507.3	700.1	16.5	1.38
24	18	409.9	668.6	15.5	1.63
25	18	394.8	592.2	15	1.5
26	18	403.5	585.5	14.5	1.45
27	18	403.5	549.9	14.5	1.36

Table 3: Tensile test results of samples from known extraction source (shaded cells indicate a failure of sample)

Bar No.	Extraction place	Specified Size (mm)	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)	Fu/Fy Ratio

Limits			400-520	min 500	min 12 %	min 1.25
1	slab	12	505.1	721.5	10	1.43
2	slab	12	519.3	662.5	6	1.28
3	slab	12	504.9	685.3	8.5	1.36
4	slab	12	432.8	694.3	8.5	1.6
5	slab	12	289.2	385.6	9.5	1.33
6	Column	12	432.8	712.3	10.5	1.65
7	Column	12	423.8	694.3	7	1.64
8	slab	12	487	708	12.5	1.45
9	slab	12	443	700	15	1.58
10	Column	12	-	735	15	0
11	Column	12	531	717	15	1.35
12	Column	12	576	691	10	1.2
13	Column	12	461	708	10	1.53
14	slab	14	-	760	5	0
15	slab	14	-	617	2	0
16	slab	14	487	747	4	1.53
17	slab	14	-	682	5	0
18	*ground beam	14	461	721	17.5	1.56
19	*ground beam	14	461	734	15	1.59
20	*ground beam	14	516	720	16	1.35
21	*ground beam	14	520	688	14	1.32
22	*ground beam	14	515	735	15.5	1.42
23	*ground beam	14	500	704	16	1.408
24	*ground beam	14	516	705	12.5	1.36
25	Column	14	448	682	15	1.52
26	Column	14	454	689	17.5	1.51
27	Column	14	-	682	7.5	0
28	slab	16	429.9	687.8	8	1.6
29	slab	16	546.3	698	10.5	1.28
30	slab	16	489.6	636	8.5	1.3
31	Column	20	448.1	746.8	12.5	1.67
32	Column	20	438.3	766.2	12.5	1.75
33	Column	20	431.8	756.5	11.5	1.75
*Under the supervision of an expert						

Table 4 shows the results of the bend and re-bend test for 27 samples collected from known extraction sources. The reults indicate that all the samples have passed the test (Fig. 5).

Table 4: The results of bend & Re-bend tests of reused steel samples.

Ø (mm)	Sample	Extraction place	Actual Ø	Pass or Fail
8	1	slab	7.73	PASS
	2	slab	7.57	PASS
	3	slab	7.71	PASS
12	4	slab	11.92	PASS
	5	slab	11.9	PASS
	6	slab	11.88	PASS
	7	slab	11.98	PASS
	8	slab	11.89	PASS
	9	slab	11.93	PASS
	10	slab	12	PASS
	11	Column	12	PASS
	12	Slab	12	PASS
14	13	Slab	14.56	PASS
	14	slab	13.67	PASS
	15	slab	14.83	PASS
	16	slab	13.72	PASS
	17	slab	14.59	PASS
	18	slab	15.32	PASS
	19	slab	15.56	PASS
	20	slab	16.33	PASS
	21	slab	15.46	PASS
	22	slab	15.38	PASS
	23	slab	16.19	PASS
	24	slab	15.56	PASS
	25	slab	16	PASS
	26	slab	16	PASS
20	27	Column	19.6	PASS

Fig. 5 Samples after bend & re-bend test

IV CONCLUSION

The possibility of applying reused steel to new constructions in Gaza has been studied in this paper through the process of re-certification; a visual inspection, a tensile test and a bend and re-bend test are performed on each reused steel bar. The results were varying depending on the site and the construction elements from which the steel bars were collected. The demolition process of the source building is another important factor affecting the quality of the steel bar. The extraction of steel bars under the supervision of a specialist has clearly enhanced the performance of reused steel bars. The steel bars extracted from ground beams under a specialist supervision did not fail any of the tensile test requirements. The bars that passed all the tests could be used in new constructions as alternatives to newly casted steel bars. In conclusion, although steel reuse is not a common practice worldwide, it is recommended to use reused steel bars in Gaza Strip after applying all the required tests to recertify the steel bar.

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