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Research Article

The effect of iron chip additive on structural behavior of under-reinforced and over-reinforced cantilever beams

Omer Fatih Sancak[1], **Muhammet Zeki Ozyurt**[2,*]

[1] Institute of Natural Sciences, Sakarya University, Sakarya (Türkiye), ofatihsancak@gmail.com
[2] Civil Engineering Department, Sakarya University, Sakarya (Türkiye), ozyurt@sakarya.edu.tr
*Correspondence: ozyurt@sakarya.edu.tr

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Abstract: This study focused on whether industrial iron chips waste can be recycled by using them in the production of reinforced concrete cantilever beams. The amount of aggregate in the range of 0-4 mm in the concrete used in the production of cantilever beams was determined. And this amount was reduced by 10%, 20% and 40% and replaced with iron chips. Cantilever beams have been produced in two different ways as under-reinforcement and over-reinforcement by changing the diameters of the tension reinforcement. Thanks to the experimental setup, the cantilever beams were loaded at their end points. In the experimental study, the load-displacement curves of the cantilever beams were obtained. According to the findings obtained in the study, under-reinforced cantilever beams behaved more ductile than over-reinforced cantilever beams. Cantilever beams with 40% iron chip additive reached the highest strength and exhibited the most brittle fracture examples. Cantilever beams containing 10% and 20% iron chip additives increased their ductility values up to 14.54% and decreased their strength up to %17.27 compared to reference cantilever beams.

Keywords: Reinforced concrete, cantilever beam, iron chip additive, ductility, structural behavior.

1. Introduction

Reinforced concrete beams with fixed support at one end and unsupported at the other end are called cantilever beams. Cantilever beams are used in various areas. Some of these can be listed as building parts such as balconies, building facades, reinforced concrete stairs, roofs and eaves (Sancak, 2021). In addition, many buildings are generally placed on cantilever protrusions after the ground floor in order to increase the floor area (Aykaç et al., 2011). For this reason, the design and application principles of cantilever beams, which are frequently used, are important. In particular, the behavior of the cantilever beam under a certain load should be known and precautions should be taken.

Cantilever beams are generally seen as extensions of normal beams in multi-storey buildings. However, they differ from normal beams in the design phase and reinforcement placement because their behavior, the loads they take on them and the moments they carry are different. In order to prevent tensile stress in cantilever beams, the main steels and bent bars are placed on top, and assembly steels are placed on the bottom. Hook angle is made on the ends of the main steel and bent bars (Sancak, 2021).

Iron chips are industrial wastes that arise as a result of various abrasions, ruptures or stripping during the production processes of iron or steel in industrial factories or lathe workshops. As a result of the increase in the world population, construction and the growth of the industry, pollution threatening natural resources has been one of the important problems of humanity. The protection of the world ecological balance is primarily through the knowledge and recognition of these problems. For this purpose, scientific studies continue to be carried out on the recycling of industrial wastes in the construction sector as well as in many other sectors. The main aim is to focus the solid waste disposal problem on reducing the use of raw materials by recycling materials as much as possible (Althoey et al., 2021; Alwaeli, 2016; Binici et al., 2015; Coskun, 2016; Dharmaraj, 2021; Furlani et al., 2016; Garg, 2022; Malek et al., 2021; Praburanganathan et al., 2022; Satyaprakash et al., 2019).

In this study, the effect of iron chips, which is an industrial waste, on reinforced concrete cantilever beams was taken as the subject. It has been investigated whether industrial iron chips waste, which will no longer be used and will be thrown into the nature, can be recycled. For this purpose, it was investigated how the behavior of cantilever beam would change by adding iron chips material to cantilever beams at different rates.

2. Creating test samples

16 samples were produced within the scope of the study. The dimensions of the samples created are designed to be 150 mm in width, 200 mm in height and 700 mm in length. The 300 mm part of the 700 mm length of the samples was designed as a column for reinforcement placement, and the 400 mm part was designed as a cantilever beam. The cover is determined as 20 mm.

In Figure 1, the image of the samples to be created as a draft is given.

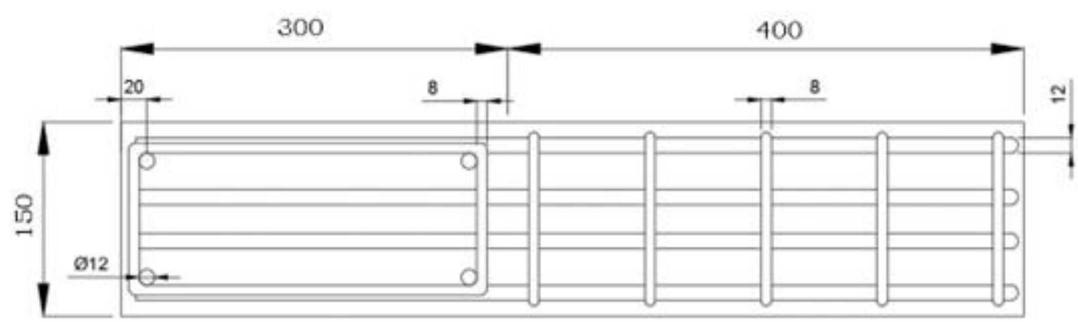


Figure 1. Reinforcement plan of cantilever beam samples.

Eight of the cantilever beams to be formed are designed to be under-reinforced and 8 of them are designed to be over-reinforced. While 12 mm diameter longitudinal reinforcement is used in cantilever beams with under-reinforcement, 16 mm diameter longitudinal reinforcement is used in cantilever beams with over-reinforcement. The diameters of the stirrup reinforcements were chosen as 8 mm, the hook angle of the stirrup hooks 135 degrees and the stirrup spacing of 100 mm in all samples created. S420 steel was used as reinforcement in all samples. The compressive strength of the concrete used in the production of the test samples was determined as 25 MPa.

Table 1 shows the material and cross-section properties of the test samples.

Table 1. Material and section properties of test samples.

	Under-reinforced	Over-reinforced
Concrete	C25	C25
Reinforcement	S420	S420
Section	150 mm x 200 mm	150 mm x 200 mm
Longitudinal rebar diameter	12 mm	16 mm
Transverse rebar diameter	8 mm	8 mm
Pressure reinforcement	2Ø12	2Ø12
Tensile rebar	4Ø12	4Ø16
Cantilever beam span	400 mm	400 mm
Stirrup hook angle	135°	135°

In the study, industrial iron chips obtained from Sakarya 1st Organized Industrial Zone were used as additives. Iron chips material was subjected to sieve analysis.

Table 2 shows the results of iron chips sieve analysis.

Table 2. Iron chips sieve analysis results.

Sieve Interval (mm)	Passing (%)
4	100
2	16.44
1	4.10
0,5	0

Approximately 21000 cm^3 of concrete was used for the samples, each 150x200x700 mm in size. The materials used in creating this concrete were 8 kg cement, 17.5 kg sand and 21.25 kg crushed stone. The stone chips to be used were chosen as number 2 stone chips. While the concrete was being formed, the specified amounts of aggregate and cement were placed in the concrete machine. Then a 4 liters' capacity container of water was filled and 2 liters of it was poured into the concrete machine. The remaining 2 liters of water was mixed with approximately 150 g plasticizer and added into the machine. The concrete machine was operated for approximately 2 minutes and the concrete required for the samples was obtained.

Small cylinder samples were taken from the concrete used in the reinforced concrete cantilever beams formed and kept in the curing pool for 28 days. The samples taken from the pool were broken and the results obtained were made into a Stress-Strain plot. The elasticity module of the concrete was calculated based on the graphics created.

Modulus of elasticity values are given in Table 3.

Table 3. Modulus of Elasticity of cylinder specimens.

Cylinder sample feature	Stress (MPa)	Strain	Modulus of Elasticity (MPa)
No additive	25.74234	0.00089122	28884.34625
	24.54351	0.00087021	28204.20728
	24.98764	0.00087360	28603.15558
	26.98564	0.00092599	29142.40597
	25.43152	0.00089890	28291.95389
	25.54326	0.00089408	28569.32599
10% Iron chips additive	26.76230	0.00090498	29572.34493
	25.52342	0.00091113	28013.03779
	24.87512	0.00087961	28279.70380
20% Iron chips additive	24.63240	0.00086369	28519.92093
	23.94363	0.00084976	28177.00541
	27.78438	0.00095328	29145.96826
	24.98642	0.00087574	28531.89315
	26.84327	0.00090966	29509.03621
	28.97362	0.00096897	29901.4381
40% Iron chips additive	27.32513	0.00092523	29533.28025
	25.42342	0.00087834	28944.71442
	26.23523	0.00090108	29115.44667

The formula for the balanced reinforcement ratio (ρ_b) is given in (Equation 1). The balanced reinforcement ratio (ρ_b) of the cantilever beam samples was calculated in (Equation 2).

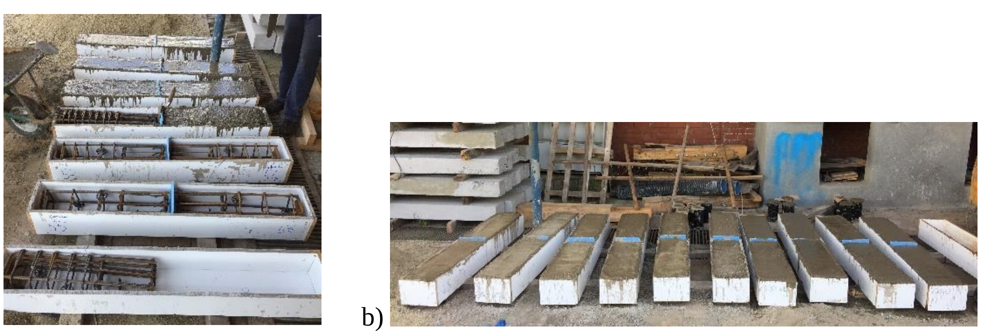
$$\rho_b = \frac{A_{sb}}{b_w d} = \frac{0.85 f_{cd}}{f_{yd}} k_1 \left(\frac{\varepsilon_{cu} E_s}{\varepsilon_{cu} E_s + f_{yd}} \right) \quad (1)$$

In (Equation 1), (ρ_b) is the balanced reinforcement ratio, (A_{sb}) is the reinforcement area corresponding to the balanced reinforcement ratio, (b_w) is the beam section width, (d) is the useful height of the beam section, (f_{cd}) is the design compressive strength, (f_{yd}) is the design reinforcement strength, (k_1) is the ratio between the average compressive stress and the maximum stress, (ε_{cu}) is the crushing unit shortening of the concrete and (E_s) the elastic modulus of the reinforcement.

$$\rho_b = \frac{0.85 \times 17}{365} 0.85 \left(\frac{0.003 \times 2 \times 10^5}{0.003 \times 2 \times 10^5 + 365} \right) = 0.0209 \quad (2)$$

Tensile reinforcement in under-reinforced samples is 4ϕ12. The reinforcement ratio was calculated as 0.01676. On the other hand, the tensile reinforcement is 4ϕ16 in the over-reinforced samples. The reinforcement ratio was calculated as 0.02979.

Figure 2 shows some samples before and after the concrete pouring.



a) b)

Figure 2. Conditions of some samples before and after concrete pouring, a) before concrete; b) after concrete.

In the nomenclature, under-reinforced samples start with the letter A, while over-reinforced samples start with the letter B. Samples with a stirrup spacing of 10 cm contain the number 10, and samples with a hook angle of 135 degrees contain the letter b. Samples without additives contain the number 1 in their names, and samples with iron chips additives contain the number 3. Samples with 0% additive content contain the letter w, 10% samples contain the letter x, 20% samples contain the letter y, and 40% samples contain the letter z.

In order to increase the accuracy of the results, two samples of the same characteristics were produced. The names of the samples with the same characteristics, which are under-reinforced, are named by starting as A1 and A2, and the names of the samples with over-reinforcement are started as B1 and B2.

In Table 4, naming details of the samples produced as under-reinforced and over-reinforced are given.

Table 4. Nomenclature detail of under-reinforced and over-reinforced samples.

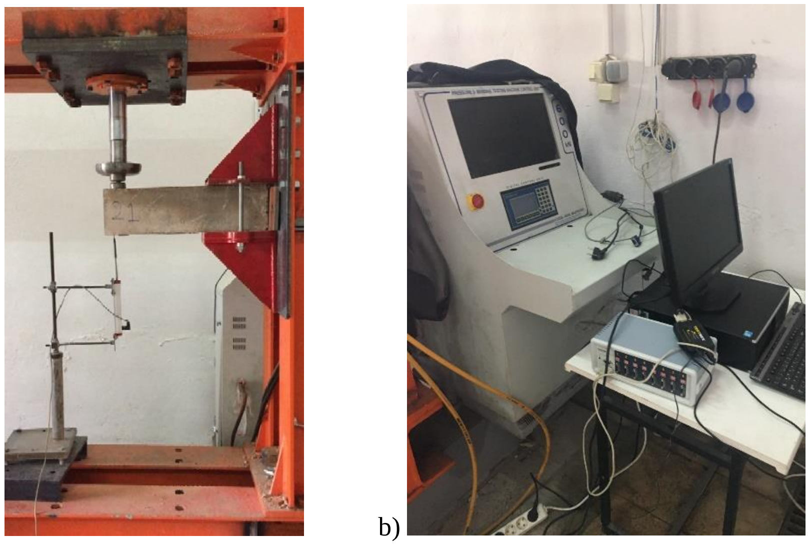
Stirrup spacing	Stirrup hook angle	Additive	Additive percentage	Sample name	
				Under-reinforced	Over-reinforced
10	135	No Additive	%0	A_1-10-b-1-w A_2-10-b-1-w	B_1-10-b-1-w B_2-10-b-1-w
		Iron chips	%10	A_1-10-b-3-x A_2-10-b-3-x	B_1-10-b-3-x B_2-10-b-3-x
			%20	A_1-10-b-3-y A_2-10-b-3-y	B_1-10-b-3-y B_2-10-b-3-y
			%40	A_1-10-b-3-z A_2-10-b-3-z	B_1-10-b-3-z B_2-10-b-3-z

3. Experimental study

The cantilever beam samples were experimentally broken at the Sakarya University Structural Mechanics Laboratory. A detailed mechanism has been prepared in order to break the cantilever beams under the steel frame. The experimental setup is based on the cantilever beam bending effect by applying a load from the end of the cantilever beam. Load cell is used to load cantilever beams in order to obtain load-displacement graphs of cantilever beams. Load cell is placed between load cell and cantilever beam. The displacement of the cantilever beam against the load applied from the end was measured with a potentiometer placed at the end and bottom of the cantilever beam. The values of the load cell and potentiometer were recorded using the Test Lab Basic program in the Sakarya University Structural Mechanics Laboratory.

The experimental setup was created by combining several parts. Two L-shaped steel parts were manufactured to hold the column part of the cantilever beam samples. It is aimed to create a built-in support for the cantilever beam by placing the samples between the parts produced in the L shape and preventing them from turning.

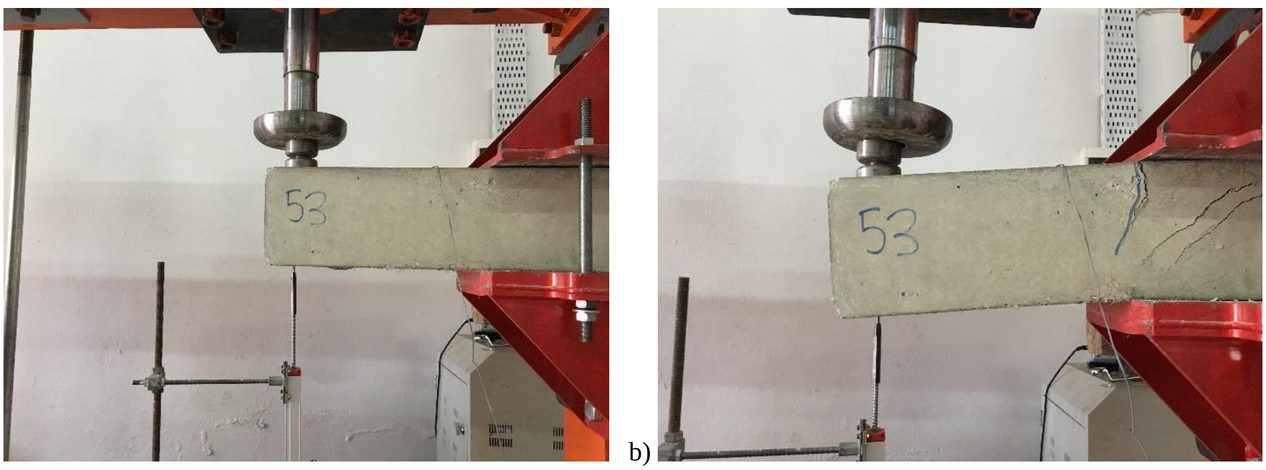
Figure 3 shows the image of the experimental setup and the computer to be used.



a) b)

Figure 3. Image of the experimental setup and the computer to be used. a) Experimental setup; b) Computer to be used.

In Figure 4, one of the samples broken in the test setup before and after the test is given.



a) b)

Figure 4. Pre-experimental and post-experimental image of a sample, a) before the experiment; b) after the experiment.

4. Experiment results

Load-Displacement graphs of the samples were obtained by using Test Lab Basic while the test specimens were fractured. Within the scope of the thesis, the results of two samples, all of which were produced with the same characteristics, were examined and graphics were created by taking their average. By taking the averaging of the reinforced concrete cantilever beams named starting from A1, A2 with under-reinforcement, their names are started as A. On the other hand, the names of the reinforced concrete cantilever beams, which are named starting from B1, B2 and which are over-reinforcement, are averaged and their names are started as B.

The ductility and maximum load values of the cantilever beams subjected to the test are given in Table 5.

Table 5. Experimental results.

Sample name	Ductility coefficient	Maximum load (kgf)
A_1-10-b-1-w	1.50369	9212.7564
A_2-10-b-1-w	1.49947	9106.8654
B_1-10-b-1-w	1.42187	10954.8921
B_2-10-b-1-w	1.41315	10568.7145
A_1-10-b-3-x	1.72175	8798.9341
A_2-10-b-3-x	1.71236	8720.6429
B_1-10-b-3-x	1.43995	8978.2391
B_2-10-b-3-x	1.43205	8909.1962
A_1-10-b-3-y	1.59843	9098.8424
A_2-10-b-3-y	1.58865	8986.3856
B_1-10-b-3-y	1.42861	9574.1274
B_2-10-b-3-y	1.42007	9475.8652
A_1-10-b-3-z	1.46864	10173.1724
A_2-10-b-3-z	1.46243	9954.3091
B_1-10-b-3-z	1.37893	12181.4363
B_2-10-b-3-z	1.37385	11734.5461

5. Comparison of experiment results

According to the data obtained as a result of the experiments, the ductility coefficients of the cantilever beam samples were calculated as given in (Equation 3). In the calculation of the ductility coefficient, the displacements at the time of yield and the maximum displacements were found using the graph given in Figure 5 (Park, 1988). In the previous study, it was shown that the maximum displacement values can be taken as the displacement values that occur as a result of the decrease of the maximum load values up to 20% (Park, 1988). However, in this study, the maximum displacement values are accepted as the displacement values that occur as a result of approximately 15% decrease in the maximum load values that cantilever beams can carry.

$$\mu = \frac{u_{max}}{u_y} \tag{3}$$

In (Equation 3), (μ) represents the ductility coefficient, (u_{max}) maximum displacement and (u_y) displacement at yield.

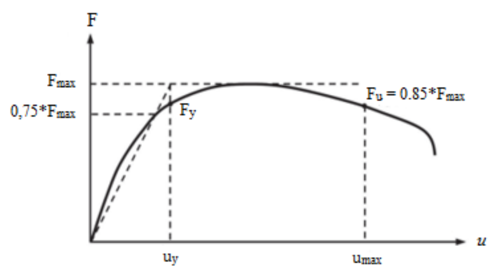


Figure 5. Load-Displacement curve taken as reference for ductility calculation (Park, 1988).

Below are the comparative graphs of the samples separated from each other according to their under-reinforced and over-reinforced states.

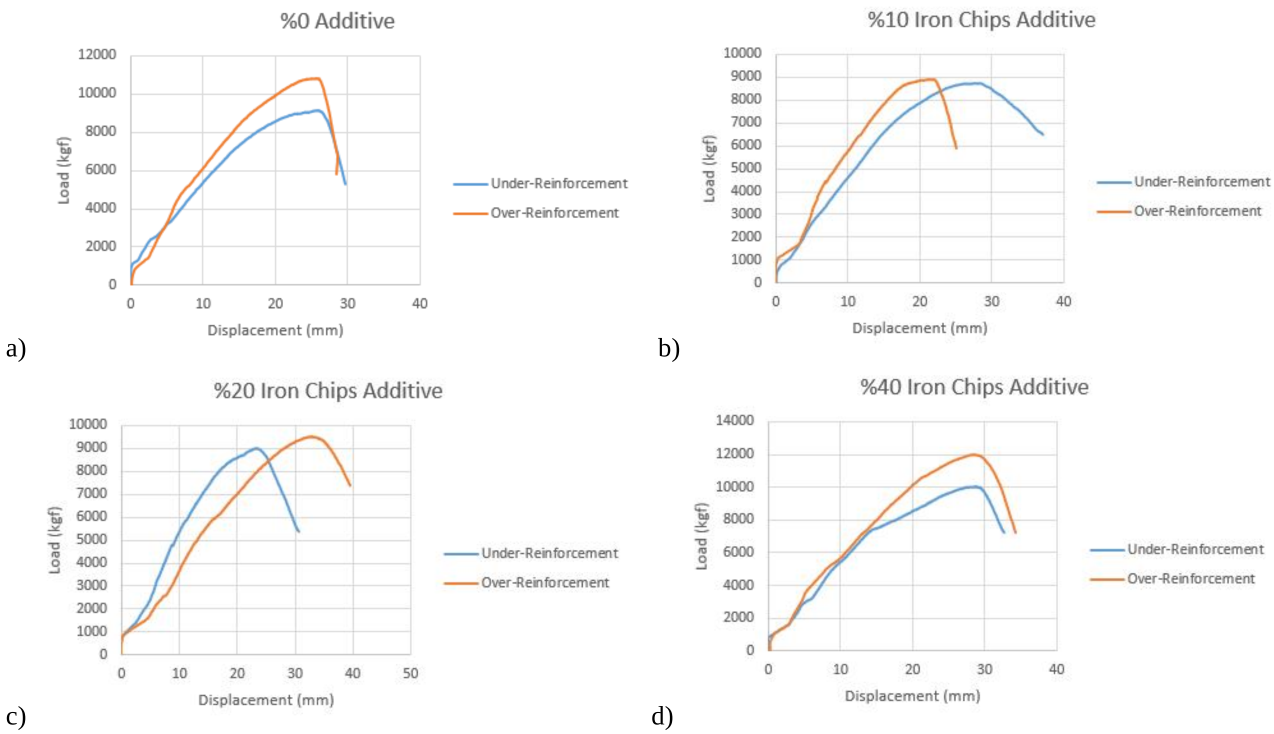


Figure 6. Comparison graphs. a) A-10-b-1-w and B-10-b-1-w; b) A-10-b-3-x and B-10-b-3-x; c) A-10-b-3-y and B-10-b-3-y; d) A-10-b-3-z and B-10-b-3-z.

Based on the results obtained, the cantilever beam samples were compared according to their under-reinforcement and over-reinforcement. The ductility values of the compared samples and the maximum loads they carry are given in Table 6. In addition, the percentage increases in the ductility values and the maximum loads they carry are given in Table 6.

Table 6. Under-reinforcement and over-reinforcement comparison chart.

Sample name	$u_{y\,(mm)}$	$u_{max\,(mm)}$	μ	Percentage increase (%)	F_{max} *(kgf)*	Percentage increase (%)
A-10-b-1-w	18.55	27.83594	1.50059	5.71332	9125.2878	-15.4794
B-10-b-1-w	19.21	27.26840	1.41949	-	10796.526	-
A-10-b-3-x	19.97	34.32364	1.71876	19.61667	8736.0750	-2.19797
B-10-b-3-x	16.47	23.66558	1.43689	-	8932.4070	-
A-10-b-3-y	18.09	28.77468	1.59064	11.72108	9043.4360	-4.87319
B-10-b-3-y	26.73	38.05710	1.42376	-	9506.7159	-
A-10-b-3-z	21.20	31.07644	1.46587	6.48946	10058.643	-15.9851
B-10-b-3-z	23.31	32.08715	1.37654	-	11972.456	-

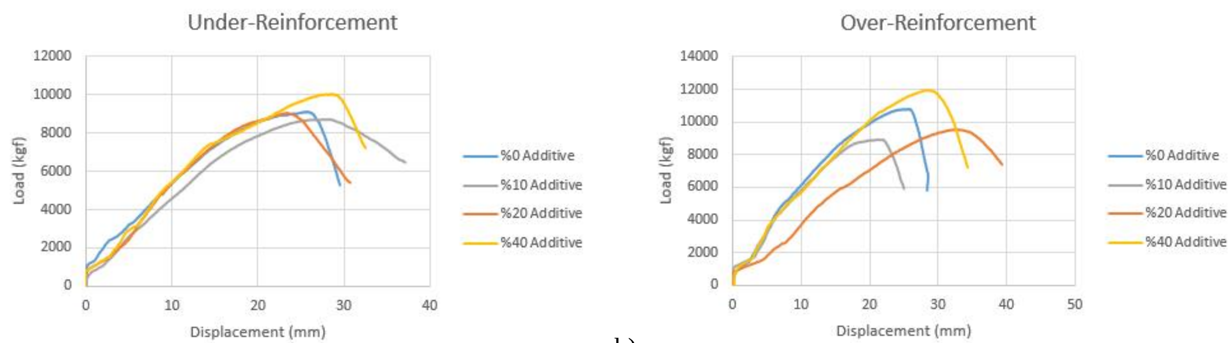
The ductility coefficients of the samples without additives with under-reinforcement increased by 5.71% compared to those formed with over-reinforcement. However, the maximum loads they carry decreased by 15.48%.

The ductility coefficients of the 10% iron chips added samples with under-reinforcement increased by 19.62% compared to the samples formed with over-reinforcement. However, the maximum loads they carry decreased by 2.20%.

The ductility coefficients of the 20% iron chips added samples with under-reinforcement increased by 11.72% compared to the samples formed with over-reinforcement. However, the maximum loads they carry decreased by 4.87%.

The ductility coefficients of the 40% iron chips added samples with under-reinforcement increased by 6.49% compared to the samples formed with over-reinforcement. However, the maximum loads they carry decreased by 15.99%.

Comparative graphics of the samples with concrete without additives and those with concrete with iron chips in different ratios are given below.



a) b)

Figure 7. Comparison graphs. a) A-10-b-1-w, A-10-b-3-x, A-10-b-3-y and A-10-b-3-z; b) B-10-b-1-w, B-10-b-3-x, B-10-b-3-y and B-10-b-3-z.

Based on the results obtained, the cantilever beam samples containing 10%, 20% and 40% iron chips additives were compared with the cantilever beam samples without additives. The ductility values of the compared samples and the maximum loads they carry are given in Table 7. In addition, the percentage increases in the ductility values and maximum loads of the samples with 10%, 20% and 40% iron chips compared to the samples without additives are given in Table 7.

Table 7. Iron chips additive comparison chart.

Sample name	$u_{y\ (mm)}$	$u_{max\ (mm)}$	μ	Percentage increase (%)	F_{max} *(kgf)*	Percentage increase (%)
A-10-b-1-w	18.55	27.83594	1.50059	-	9125.288	-
A-10-b-3-x	19.97	34.32364	1.71876	14.53895	8736.075	-4.26521
A-10-b-3-y	18.09	28.77468	1.59064	6.000973	9043.436	-0.89698
A-10-b-3-z	21.2	31.07644	1.46587	-2.313760	10058.64	10.2282
B-10-b-1-w	19.21	27.2684	1.41949	-	10796.53	-
B-10-b-3-x	16.47	23.66558	1.43689	1.225792	8932.407	-17.2659
B-10-b-3-y	26.73	38.05710	1.42376	0.300812	9506.716	-11.9465
B-10-b-3-z	23.31	32.08715	1.37654	-3.025730	11972.46	10.8917

Among the under-reinforced samples, the ductility coefficients of the samples with 10% iron chips additive increased by 14.54% compared to the ones without additives. However, the maximum loads they carry decreased by 4.27%.

Among the under-reinforced samples, the ductility coefficients of the samples with 20% iron chips additive increased by 6.00% compared to the ones without additives. However, the maximum loads they carry decreased by 0.90%.

Among the under-reinforced samples, the ductility coefficients of the samples with 40% iron chips additive decreased by 2.31% compared to the ones without additives. However, the maximum loads they carry increased by 10.23%.

Among the over-reinforced samples, the ductility coefficients of the samples with 10% iron chips additive increased by 1.23% compared to the ones without additives. However, the maximum loads they carry decreased by 17.27%.

Among the over-reinforced samples, the ductility coefficients of the samples with 20% iron chips additive increased by 0.30% compared to the ones without additives. However, the maximum loads they carry decreased by 11.95%.

Among the over-reinforced samples, the ductility coefficients of the samples with 40% iron chips additive decreased by 3.03% compared to the ones without additives. However, the maximum loads they carry increased by 10.89%.

In another study (Alwaeli et al., 2012), 25%, 50%, 75% and 100% iron chips waste were placed in the samples instead of sand, and their compressive strengths increased by 24.34%, 29.63%, 42.86% and 50.79%, respectively.

In a similar study (Satyapraaskh et al., 2019.), sand was replaced by iron chips at 10%, 20%, 30%, 50%, 70%, 80% and 100%. The strengths of the samples were tested by breaking after 7, 14 and 28-day cures. All of the iron chips added samples increased their strength compared to the undoped reference samples. As the percentage of iron chips additive increased, the strength values also increased.

In the study conducted within the scope of the article, it was observed that the 10% and 20% iron chips added samples lost their strength compared to the reference samples, and the strength was increased in the 40% added samples.

In another study (Kashkool et al., 2021), polymer modified concrete was discussed. It was observed that the compressive strength of ordinary polymer concrete increased by 29.84% as a result of replacing 40% of the sand in it with waste iron chips.
In the study conducted within the scope of the article, it was seen that this ratio was 10.23% and 10.89% for under-reinforced and over-reinforced beams, respectively.

6. Conclusions

Within the scope of the thesis study, cantilever beams, which are frequently used in buildings, were produced by changing their various properties. Cantilever beams are manufactured with under-reinforcement and over-reinforcement, and the effect of this on the behavior of the cantilever beam has been investigated. In addition, 10%, 20% and 40% iron chips additives were added instead of the aggregate used in the production of the cantilever beam, and the effects of this additive on the behavior of the cantilever beam were discussed as a result of the experimental data.

As a result of the experiments, the following conclusions can be drawn:

1. It was observed that the samples produced with under-reinforcement exhibited a more ductile behavior between 5.71% and 19.62% compared to the ones produced with over-reinforcement.
2. Although the maximum loads of the samples produced with over-reinforcement were between 2.20%-15.99% higher than those produced with under-reinforcement, they caused brittle fracture. Regulations do not allow for over-reinforcement design. Cantilever beams should be produced with under-reinforcement according to experimental results and regulations.
3. Reinforced concrete cantilever beams with 10% iron chips have the lowest value, reducing the maximum loads they carry by 4.27% and 17.27% compared to the reference samples. At the same time, they showed the most ductile behavior by increasing their ductility values by 14.54% and 1.23%.
4. Reinforced concrete cantilever beams with 20% iron chips experienced 0.90% and 11.95% reductions in strength compared to the reference samples and increased their ductility values by 6.00% and 0.30%.
5. Reinforced concrete cantilever beams with 40% iron chips have the highest value by increasing their maximum loads by 10.23% and 10.89% compared to the reference samples. At the same time, they showed the most brittle behavior by decreasing their ductility values by 2.31% and 3.03%.

The study focused on the behavior of the cantilever beam, which is a structural element, rather than classical compressive strength tests of concrete. When there is a demand for ductility from cantilever beams at the design stage, it has been seen that it would be beneficial to produce cantilever beams with 10% and 20% iron chips. In addition, it has been observed that 40% iron chips additive can be beneficial in cases where the demand for strength is required.

References

Althoey, F., Hosen, M. A. (2021). Physical and mechanical characteristics of sustainable concrete comprising industrial waste materials as a replacement of conventional aggregate. Sustainability, *13*(8), 4306.

Alwaeli M., Nadziakiewicz J. (2012). Recycling of Scale and Steel Chips Waste as a Partial Replacement of Sand in Concrete. Construction and Building Materials 28, 157–163.

Alwaeli M. (2016). The implementation of scale and steel chips waste as a replacement for raw sand in concrete manufacturing. Journal of Cleaner Production 137:1038–1044.

Aykaç, S., Aykaç, B., Ekinci, Y. (2011). BA yapilarda konsol kirişlere aktarilan ilave yükler. Teknik Dergi, 5449-5462, 351.

Binici, H., Sevinç, A. H., Geçkil, H. (2015). Atık Demir Tozu Katkılı Harç ve Betonların Durabilite Özellikleri. Çukurova University Journal of the Faculty of Engineering and Architecture, 30(1), pp. 1-16, June.

Cosgun, T. (2016). An experimental study of RC beams with varying concrete strength classes externally strengthened with CFRP composites. Journal of Engineered Fibers and Fabrics, 11(3), 155892501601100302.

Dharmaraj, R. (2021). Experimental study on strength and durability properties of iron scrap with fly ash based concrete. Materials today: proceedings, 37, 1041-1045.

Furlani, E., Maschio, S. (2016). Steel scale waste as component in mortars production: An experimental study. Case Studies in Construction Materials 4:93-101.

Garg, H. (2022). Durability of concrete made with steel filings as a replacement of fine aggregate. Materials Today: Proceedings, 49, 3217-3221.

Kashkool, M. J., Almadi, W. A., Jabal, Q. A., Al Asadi, L. A. R., Alghurabi, J. K. (2021). Some Mechanical Properties of Polymer Modified Concrete by Adding Waste Iron Filings and Chips. Key Engineering Materials ISSN: 1662-9795, Vol. 895, pp 110-120.

Malek, M., Kadela, M., Terpilowski, M., Szewczyk, T., Lasica, W., Muzolf, P. (2021). Effect of metal lathe waste addition on the mechanical and thermal properties of concrete. Materials 14(11):2760.

Park, R. (1988). Ductility Evaluation from Laboratory and Analytical Testing. Proceedings of the 9th World Conference on Earthquake Engineering, Tokyo, Kyoto, 8, 605-616.

Praburanganathan, S., Chithra, S., Divyah, N., Sudharsan, N., Simha, Y. and Vigneshwaran, S. (2022). Value-added waste substitution using slag and rubber aggregates in the sustainable and eco-friendly compressed brick production. Revista de la Construcción. Journal of Construction, 21(1), 5-20.

Sancak, O. F. (2021). Demir talaşı katkılı betonların ve etriye kanca açısının konsol kirişlerin yapısal davranışına etkisi. Sakarya University, Institute of Natural Science, Master's Thesis.

Satyaprakash, Helmand, P., Saini, S. (2019). Mechanical Properties of Concrete in Presence of Iron Filings as Complete Replacement of Fine Aggregates. Materials Today: Proceedings Volume 15, Part 3, Pages 536-545.