The Effect of Changing Stirrup Spacing and Hook Angle on RC Cantilever Beams with Industrial Iron Chips Waste

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Research Article

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Abstract

In this study, the usability of industrial iron chips waste was investigated in order to provide recycling in the production of reinforced concrete cantilever beams with different stirrup spacing and hook angle. In the concrete produced for cantilever beams, aggregates not larger than 4 mm in diameter were reduced by 20% and replaced with iron chips waste. Cantilever beams are manufactured with stirrup spaces of 50, 100 and 150 mm. The hook angles of the stirrups are differentiated to be 90 and 135 degrees. The experimental setup was prepared in such a way that one side of the samples was fixed, and the other side was free. The loading process was done from the end point of the released side. Load-Displacement curves of cantilever beams were obtained. In the research, it was observed that although 20% iron chips added cantilever beams experienced a decrease in their strength compared to the reference beams, they increased their ductility values at all three different stirrup spaces. As the stirrup spacing widened, the ductility values decreased. However, the effect of iron chips additive on ductility has increased. Samples with stirrup hook angle of 135 degrees increased both strength and ductility values compared to samples with 90 degrees.

1. Introduction

Technological developments in recent years have enabled the proliferation and development of industries. The rapid increase in the world population has increased consumerism in society. For this reason, the amount of waste material coming out of the industries has reached great proportions. A significant portion of industrial solid waste is generated through the iron and steel industry. Such solid wastes are generally formed in iron and steel production facilities, but they can also occur due to various workshops [3, 4, 6, 8, 12, 14].

There are different ways to reduce the waste generated because of industrial processes. Some of these are the limitation of production by the places that produce waste material, the recovery of the wastes that can be recovered, and various recycling methods. Iron and steel waste are frequently used materials for recycling [1, 3, 9].

In many countries, the rapid decline of natural resources has restricted access to raw materials and caused raw material prices to increase. For this reason, the use of industrial waste materials as raw materials by recycling methods in the construction sector has been a logical way [4, 5, 9]. Reusing iron and steel waste as aggregate substitute in concrete production will reduce the need for raw materials from natural sources. Conservation of natural resources contributes to sustainable development for future generations [8, 13].

In previous studies on this subject [8], iron wastes were investigated instead of sand in concrete. Substitution rates were determined as 10%, 15% and 20%. Samples containing iron waste were prepared and subjected to various tests. As a result of the experiments, the highest flexural strength and compressive strength were found in the samples with 20% iron waste additives.
In another study [10], the replacement rates of iron waste for sand in concrete were determined as 10%, 20%, and 30%. As a result of the experiments, 20% iron waste added samples increased their compressive strength by 13.5% and flexural strength by 4.8%.

In another study [7], granite powder and iron powder replacement percentages were determined as 5%, 10%, 15% and 20%. Samples were tested after 7 days and 28 days. Samples with 20% iron powder added increased their compressive strength by 33.3% for 7 days and by 33.2% for 28 days. In flexural strengths, these rates were 45.1% for 7 days and 44.9% for 28 days.

In the other study [2], lathe iron waste dusts were substituted for fine aggregate in concrete by 5%, 10%, 15% and 20%. As a result of the 20% substitution process, 38% increase in compressive strength and 19% increase in flexural strength has been achieved.

Academic studies dealing with the use of iron waste in concrete for recycling show that 20% iron waste substitution can be more efficient than other rates. Studies have generally focused on compressive strength tests and flexural strength tests. The fact that the additive directly affects the behavior of the building material should be known and its effect on the behavior of the building element should be examined indirectly. However, the reaction of the additive to the building elements with different properties should be considered.

In this study, iron chips waste, which is frequently created by the iron and steel industry, has been substituted for aggregate in concrete by 20%. The effect of this situation on the behavior of cantilever beams has been taken as a subject. It has been investigated whether the recycling of iron chips waste from industrial factories can be achieved. The spacing and hook angles of the stirrups used in the production of cantilever beams were changed and the effect of iron chips on various stirrup spacing and hook angles was investigated.

2. Experimental

2.1 Creating Test Samples

Within the scope of the study, 12 samples were produced. The dimensions of the samples were designed to be 150 mm wide, 200 mm high and 700 mm long. 300 mm of the length of the samples was designed as a column for reinforcement placement and 400 mm as a cantilever beam.

6 of the cantilever beams are designed with 20% iron chips added, and 6 of them are designed without additives. While the stirrup hook angle of 3 of the samples without additives was 90 degrees, 3 of them were formed as 135 degrees. The same process was repeated for the samples with 20% iron chips added. S420 steel was used in all samples. Diameter of transverse reinforcement was determined as 8 mm and diameter of longitudinal reinforcement was determined as 12 mm. 4 tension rebar and 2 compression rebar are used. Fig. 1. shows the reinforcement layout of the samples. Table 1. shows the material and cross-section properties of the test samples.
Table 1
Material and Section Properties of Test Samples.

| Properties         | Values  |
|--------------------|---------|
| Reinforcement      | S420    |
| Longitudinal rebar diameter | 12 mm   |
| Transverse rebar diameter  | 8 mm    |
| Compression rebar  | 2Ø12    |
| Tension rebar      | 4Ø12    |
| Section            | 150 mm x 200 mm |
| Hook angle         | 90˚ and 135˚ |

In the research, industrial iron chips material obtained from Sakarya 1st Organized Industrial Zone was used. The image of the iron chips is given in Fig. 2. The iron chips material was subjected to sieve analysis. The results of sieve analysis of iron chips are given in Table 2.

Table 2
Iron Chips Sieve Analysis Results.

| Sieve interval (mm) | Passing (%) |
|---------------------|-------------|
| 4                   | 100         |
| 2                   | 16.44       |
| 1                   | 4.10        |
| 0.5                 | 0           |

Within the scope of the study, the materials used while creating this concrete were 8 kg of cement, 17.5 kg of sand and 21.25 kg of stone chips. The stone chips to be used were chosen as the number 2 stone chips. While creating the samples with additives, the aggregates were subjected to sieve analysis and the aggregate amount in the range of 0-4 mm was determined. The determined amount was reduced by 20% and iron chips substitution was carried out. It was mixed with 4 liters of water in the concrete machine and concrete was obtained. In Fig. 3., the view of the concrete machine before and after operation is given.

Small cylindrical samples were taken from the concrete used in reinforced concrete cantilever beams and kept in the curing pool for 28 days. At the end of 28 days, the samples were broken, and the Stress-Strain graph was obtained. The modulus of elasticity of concrete was calculated from the graphs. The obtained elasticity modules are given in Table 3.
Table 3
Modules 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                |
| 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 | 29901.43810                |

In nomenclature, samples with stirrup spacing of 50, 100 and 150 mm contain numbers 50, 100 and 150, respectively. Samples without additives contain the letter R in their names, and samples with %20 iron chips additives have the letters IC. Samples with a stirrup hook angle of 90 degrees contain the number 90, and samples with 135 degrees contain the number 135. The naming details of the produced samples are given in Table 4.
Table 4  
Nomenclature Detail of The Samples.

| Stirrup spacing (mm) | Additive          | Hook angle | Sample name |
|----------------------|-------------------|------------|-------------|
| 50                   | No Additive       | 90         | 50-R-90     |
| 50                   | No Additive       | 135        | 50-R-135    |
| 100                  | No Additive       | 90         | 100-R-90    |
| 100                  | No Additive       | 135        | 100-R135    |
| 150                  | No Additive       | 90         | 150-R-90    |
| 150                  | No Additive       | 135        | 150-R-135   |
| 50                   | %20 Iron Chips    | 90         | 50-IC-90    |
| 50                   | %20 Iron Chips    | 135        | 50-IC-135   |
| 100                  | %20 Iron Chips    | 90         | 100-IC-90   |
| 100                  | %20 Iron Chips    | 135        | 100-IC-135  |
| 150                  | %20 Iron Chips    | 90         | 150-IC-90   |
| 150                  | %20 Iron Chips    | 135        | 150-IC-135  |

2.2 Experimental Setup

Experimental breaking of cantilever beam samples was carried out in Sakarya University Structural Mechanics Laboratory. The experimental setup is based on bending the cantilever beam by applying a load from the end of the cantilever beam. The applied load was measured by the load cell and the displacement was measured by the potentiometer. The values in the potentiometer with the load cell were recorded using the Test Lab Basic program. The image of the experimental setup is given in Fig. 4. In Fig. 5., the pre-experiment and post-experiment view of one of the samples is given.

3. Results And Discussion

Load-Displacement graphs of the samples were obtained by using Test Lab Basic while breaking the test samples. The ductility coefficients and maximum load values of the cantilever beams are given in Table 5.
Table 5
Experimental Results.

| Sample name | Ductility coefficient | Maximum load (kgf) |
|-------------|-----------------------|--------------------|
| 50-R-90     | 1.520                 | 9428.1879          |
| 50-R-135    | 1.599                 | 9752.7836          |
| 100-R-90    | 1.454                 | 8695.7976          |
| 100-R-135   | 1.500                 | 9125.2878          |
| 150-R-90    | 1.370                 | 8004.8826          |
| 150-R-135   | 1.411                 | 8400.2250          |
| 50-IC-90    | 1.548                 | 9312.6545          |
| 50-IC-135   | 1.619                 | 9618.7382          |
| 100-IC-90   | 1.488                 | 8562.6194          |
| 100-IC-135  | 1.590                 | 8998.9661          |
| 150-IC-90   | 1.437                 | 7894.3892          |
| 150-IC-135  | 1.567                 | 8297.5438          |

The ductility coefficients of the cantilever beam samples were calculated as given in Eq. (1). In the calculation of the ductility coefficient, the displacements at the time of yield and the maximum displacements were calculated as given in Fig. 6. [11]. In Eq. (1), \( \mu \) represents the ductility coefficient, \( u_{\text{max}} \) the maximum displacement and \( u_y \) the displacement at the time of yield.

\[
\mu = \frac{u_{\text{max}}}{u_y} \tag{1}
\]

Below are the comparative graphics of the samples separated from each other according to their no additive and 20% iron chips added status.
Table 6
%20 Iron Chips Additive Comparison Chart.

| Sample name | \( u_y \) (mm) | \( u_{\text{max}} \) (mm) | \( \mu \) | Percentage increase (%) | \( F_{\text{max}} \) (kgf) | Percentage increase (%) |
|-------------|----------------|----------------|--------|-------------------------|----------------|-------------------------|
| 50-R-90     | 17.89          | 27.20          | 1.520  | -                       | 9428.1879      | -                       |
| 50-IC-90    | 22.63          | 35.02          | 1.548  | 1.8421                  | 9312.6545      | -1.2254                 |
| 50-R-135    | 18.38          | 29.40          | 1.599  | -                       | 9752.7836      | -                       |
| 50-IC-135   | 22.39          | 36.25          | 1.619  | 1.2508                  | 9618.7382      | -1.3744                 |
| 100-R-90    | 19.27          | 28.02          | 1.454  | -                       | 8695.7976      | -                       |
| 100-IC-90   | 21.82          | 32.46          | 1.488  | 2.3384                  | 8562.6194      | -1.5315                 |
| 100-R-135   | 18.55          | 27.84          | 1.500  | -                       | 9125.2878      | -                       |
| 100-IC-135  | 18.09          | 28.78          | 1.590  | 6.0000                  | 8998.9661      | -1.3843                 |
| 150-R-90    | 17.79          | 24.37          | 1.370  | -                       | 8004.8826      | -                       |
| 150-IC-90   | 18.95          | 27.23          | 1.437  | 4.8905                  | 7894.3892      | -1.3803                 |
| 150-R-135   | 21.1           | 29.78          | 1.411  | -                       | 8400.2250      | -                       |
| 150-IC-135  | 21.19          | 33.21          | 1.567  | 11.0560                 | 8297.5438      | -1.2224                 |

The ductility values of the samples and the maximum loads they carry are given in Table 6. In addition, the percentage increases in the ductility values and maximum loads of the samples with additive compared to the samples without additive are given.

The ones with additives of the samples with a stirrup spacing of 50 mm and hook angle of 90 degrees increased their ductility coefficient by 1.84% compared to the ones without additives. However, their strength decreased by 1.23%.

The ones with additives of the samples with a stirrup spacing of 50 mm and hook angle of 135 degrees increased their ductility coefficient by 1.25% compared to the ones without additives. However, their strength decreased by 1.37%.

The ones with additives of the samples with a stirrup spacing of 100 mm and hook angle of 90 degrees increased their ductility coefficient by 2.34% compared to the ones without additives. However, their strength decreased by 1.53%.

The ones with additives of the samples with a stirrup spacing of 100 mm and hook angle of 135 degrees increased their ductility coefficient by 6.00% compared to the ones without additives. However, their strength decreased by 1.38%.
The ones with additives of the samples with a stirrup spacing of 150 mm and hook angle of 90 degree increased their ductility coefficient by 4.89% compared to the ones without additives. However, their strength decreased by 1.38%.

The ones with additives of the samples with a stirrup spacing of 150 mm and hook angle of 135 degree increased their ductility coefficient by 11.06% compared to the ones without additives. However, their strength decreased by 1.22%.

Comparative graphics of the samples separated from each other by the stirrup hook angles are given below.

The ductility values of the 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 stirrup hook angle 135 degrees compared to the samples with stirrup hook angle 90 degrees are given.

Table 7
Stirrup Hook Angle Comparison Chart.

| Sample name | $u_y$ (mm) | $u_{max}$ (mm) | $\mu$ | Percentage increase (%) | $F_{max}$ (kgf) | Percentage increase (%) |
|-------------|------------|----------------|------|-------------------------|----------------|-------------------------|
| 50-R-90     | 17.89      | 27.20          | 1.520| -                       | 9428.1879      | -                       |
| 50-R-135    | 18.38      | 29.40          | 1.599| 5.1974                  | 9752.7836      | 3.4428                  |
| 100-R-90    | 19.27      | 28.02          | 1.454| -                       | 8695.7976      | -                       |
| 100-R-135   | 18.55      | 27.84          | 1.500| 3.1637                  | 9125.2878      | 4.9391                  |
| 150-R-90    | 17.79      | 24.37          | 1.370| -                       | 8004.8826      | -                       |
| 150-R-135   | 21.1       | 29.78          | 1.411| 2.9927                  | 8400.2250      | 4.9388                  |
| 50-IC-90    | 22.63      | 35.02          | 1.548| -                       | 9312.6545      | -                       |
| 50-IC-135   | 22.39      | 36.25          | 1.619| 4.5866                  | 9618.7382      | 3.2868                  |
| 100-IC-90   | 21.82      | 32.46          | 1.488| -                       | 8562.6194      | -                       |
| 100-IC-135  | 18.09      | 28.78          | 1.590| 6.8548                  | 8998.9661      | 5.0959                  |
| 150-IC-90   | 18.95      | 27.23          | 1.437| -                       | 7894.3892      | -                       |
| 150-IC-135  | 21.19      | 33.21          | 1.567| 9.0466                  | 8297.5438      | 5.1068                  |

For the samples with a 50 mm stirrup spacing and without additives, the samples with stirrup hook angle 135 degrees increased their ductility coefficient by 5.19% compared to the samples with stirrup hook angle 90 degrees. And their strength increased by 3.44%.
For the samples with a 100 mm stirrup spacing and without additives, the samples with stirrup hook angle 135 degrees increased their ductility coefficient by 3.16% compared to the samples with stirrup hook angle 90 degrees. And their strength increased by 4.94%.

For the samples with a 150 mm stirrup spacing and without additives, the samples with stirrup hook angle 135 degrees increased their ductility coefficient by 2.99% compared to the samples with stirrup hook angle 90 degrees. And their strength increased by 4.94%.

For the samples with a 50 mm stirrup spacing and with additives, the samples with stirrup hook angle 135 degrees increased their ductility coefficient by 4.57% compared to the samples with stirrup hook angle 90 degrees. And their strength increased by 3.29%.

For the samples with a 100 mm stirrup spacing and with additives, the samples with stirrup hook angle 135 degrees increased their ductility coefficient by 6.85% compared to the samples with stirrup hook angle 90 degrees. And their strength increased by 5.10%.

For the samples with a 150 mm stirrup spacing and with additives, the samples with stirrup hook angle 135 degrees increased their ductility coefficient by 9.05% compared to the samples with stirrup hook angle 90 degrees. And their strength increased by 5.11%.

### Table 8
Stirrup Spacing Comparison Chart.

| Sample Name | $u_y$ (mm) | $u_{max}$ (mm) | $\mu$ | Percentage Increase (%) | $F_{max}$ (kgf) | Percentage Increase (%) |
|-------------|------------|----------------|------|-------------------------|----------------|-------------------------|
| 150-R-90    | 17.79      | 24.37          | 1.370| -                       | 8004.8826      | -                       |
| 100-R-90    | 19.27      | 28.02          | 1.454| 6.1314                  | 8695.7976      | 8.6312                  |
| 50-R-90     | 17.89      | 27.20          | 1.520| 10.9489                 | 9428.1879      | 17.7805                 |
| 150-R-135   | 21.1       | 29.78          | 1.411| -                       | 8400.2250      | -                       |
| 100-R-135   | 18.55      | 27.84          | 1.500| 6.3076                  | 9125.2878      | 8.6315                  |
| 50-R-135    | 18.38      | 29.40          | 1.599| 13.3239                 | 9752.7836      | 16.1015                 |
| 150-IC-90   | 18.95      | 27.23          | 1.437| -                       | 7894.3892      | -                       |
| 100-IC-90   | 21.82      | 32.46          | 1.488| 3.5491                  | 8562.6194      | 8.4646                  |
| 50-IC-90    | 22.63      | 35.02          | 1.548| 7.7244                  | 9312.6545      | 17.9655                 |
| 150-IC-135  | 21.19      | 33.21          | 1.567| -                       | 8297.5438      | -                       |
| 100-IC-135  | 18.09      | 28.78          | 1.590| 1.4678                  | 8998.9661      | 8.4534                  |
| 50-IC-135   | 22.39      | 36.25          | 1.619| 3.3184                  | 9618.7382      | 15.9227                 |
Comparative graphics of the samples separated from each other by the stirrup spacing are given Fig. 19.

The ductility values of the samples and the maximum loads they carry are given in Table 8. In addition, the percentage increases in the ductility values and maximum loads of the samples with stirrup spacing 50 and 100 mm compared to the samples with stirrup spacing 150 mm are given.

Among the samples with stirrup hook angle 90 and no additives, the samples with stirrup spacing 100 mm increased their ductility coefficient by 6.13% compared to the samples with stirrup spacing 150 mm. In addition, their strength increased by 8.63%. If the stirrup spacing is 50 mm, these values are 10.95% and 17.78%, respectively.

Among the samples with stirrup hook angle 135 and no additives, the samples with stirrup spacing 100 mm increased their ductility coefficient by 6.31% compared to the samples with stirrup spacing 150 mm. In addition, their strength increased by 8.63%. If the stirrup spacing is 50 mm, these values are 13.32% and 16.10%, respectively.

Among the samples with stirrup hook angle 90 and %20 iron chips additives, the samples with stirrup spacing 100 mm increased their ductility coefficient by 3.55% compared to the samples with stirrup spacing 150 mm. In addition, their strength increased by 8.46%. If the stirrup spacing is 50 mm, these values are 7.72% and 17.97%, respectively.

Among the samples with stirrup hook angle 135 and %20 iron chips additives, the samples with stirrup spacing 100 mm increased their ductility coefficient by 1.47% compared to the samples with stirrup spacing 150 mm. In addition, their strength increased by 8.45%. If the stirrup spacing is 50 mm, these values are 3.32% and 15.92%, respectively.

4. Conclusions

The study focused on the behavior of the cantilever beam, which is a structural element, rather than compressive strength tests of concrete. Within the scope of the study, cantilever beams were produced by changing the stirrup spacing and hook angle. In addition, 20% iron chips was added instead of the aggregate used in the production of cantilever beams, and the effects of this additive on the behavior of the cantilever beam were discussed because of experimental data.

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

1. It has been observed that the 20% iron chips substitution in the concrete used in the production of cantilever beams with various stirrup spacing and hook angle reduces the strength at low rates but contributes to the ductile behavior.

2. While the positive effect of 20% iron chips additive on the ductility coefficients remained at the rate of 1.25% in samples with a stirrup spacing of 50 mm, this rate reached up to 11.06% in samples of 150 mm. The positive effect of the additive was greater in the samples exhibiting more brittle behavior.
3. The narrowing of the stirrup spacing gave positive results by increasing both the ductility values and the maximum loads of the cantilever beams with and without additives.

4. The effect of narrowing the stirrup spacing on increasing the ductility coefficients was 13.32% in samples without additive, while this rate was 7.72% in samples with %20 iron chips additive. Its effect on increasing the strength values was similar with the rates of 17.78% and 17.97% in the samples with and without additives.

5. Making the stirrup hook angle of 135 degrees instead of 90 in all samples caused the ductility values to increase between 2.99% and 9.05%. In strength values, these rates were 3.29% and 5.11%.

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**Figures**

![Figure 1](image)

**Figure 1**

Reinforcement layout of cantilever beam samples.
Figure 2

The image of the iron chips.

Figure 3

Concrete machine: (a) Before operation, (b) After operation.
Figure 4

Experimental setup.
Figure 5

One of the test samples: (a) Pre-experiment, (b) Post-experiment.
Figure 6

Load-Displacement curve referenced for ductility calculation.

Figure 7

50-R-90 and 50-IC-90 comparison graph.

Figure 8

50-R-135 and 50-IC-135 comparison graph.

Figure 9

100-R-90 and 100-IC-90 comparison graph.

Figure 10

100-R-135 and 100-IC-135 comparison graph.
Figure 11
150-R-90 and 150-IC-90 comparison graph.

Figure 12
150-R-135 and 150-IC-135 comparison graph.

Figure 13
50-R-90 and 50-R-135 comparison graph.

Figure 14
50-IC-90 and 50-IC-135 comparison graph.

Figure 15
100-R-90 and 100-R-135 comparison graph.

Figure 16
100-IC-90 and 100-IC-135 comparison graph.

Figure 17
150-R-90 and 150-R-135 comparison graph.

Figure 18
150-IC-90 and 150-IC-135 comparison graph.

**Figure 19**

Comparison graph: (a) 50-R-90, 100-R-90, 150-R-90, (b) 50-R-135, 100-R-135, 150-R-135, (c) 50-IC-90, 100-IC-90, 150-IC-90, (d) 50-IC-135, 100-IC-135, 150-IC-135.