Strength and deflection characteristics of concrete reinforced with steel swarf

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Abstract: This paper reports the strength characteristics of concrete reinforced with steel swarf at varying percentages. A total of forty-five concrete specimens were investigated; with a mix proportion of 1:2:4 and water-cement ratio of 0.55, fifteen numbers each of 150mm concrete cubes, 150x300mm concrete cylinders and 150x150x750mm beams, were cast and tested for density, compressive, tensile and flexural strengths. The results showed that workability of Swarf Reinforced Concrete (SRC) is not significantly affected at 0.5% steel swarf content but decreased as the percentage of steel swarf increased. The density of SRC increased as the percentage of fibres increased, due to the material property of the steel swarf. The compressive strength of swarf concrete as compared to normal concrete was found to increase by 1.7%, 4.8% and 5.6% for 1%, 1.5% and 2% swarf content respectively. The obtained increase in the tensile strength was 5.2%, 3.9%, 13% and 26% for 0.5%, 1%, 1.5% and 2% swarf content respectively. Using regression analysis, Index models for compressive strength and tensile strength with respect to the swarf content was developed at high coefficient of correlations ($R^2$ values) of 0.9398 and 0.9601 respectively. The maximum failure load recorded for swarf concrete was 2.5 times higher than that of plain concrete. The significant increase in the failure loads for the 1.5% and 2% steel swarf content is an indication that there was good bond between the concrete and the steel swarf. The maximum deflection of 0.57mm was recorded for swarf concrete beams. This is an increase of 103% compared to plain concrete beams. The SRC is able to sustain further deformation under increased load; this is as a result of increased load carrying capacity and ductility of the beam section, which is due to the strength and ductility properties of the embedded steel swarf.

Keywords: Concrete, Steel Swarf, Flexural Strength, Compressive Strength, Tensile Strength, Deflection, Regression Model

1.0 INTRODUCTION

Many attempts have been made to increase the tensile strength of concrete; one of the most efficient and commonly used methods is fibre reinforcement. The regular reinforcing steel bars only guide against local tension. When cracks occur in reinforced concrete, they penetrate freely within the concrete until encountering a rebar. Rebars are usually not so closely spaced and are only a relatively small fraction of the total area of reinforced concrete, they therefore cannot prevent free extension of cracks. Thus the need arises for a closely spaced steel reinforcement, which are multidirectional; and this cannot be practically provided on site. Fibre reinforcement adequately meets this challenge. A wide variety of material have been researched and formulated for the production of Fibre Reinforced Concrete (FRC), [1, 2].

It has been reported [3] that the introduction of polyvinyl alcohol (PVA) fibres in concrete decreased the workability of the mix. With a fibre volumetric content equal or greater than 0.5%, the workability decreased substantially. It was further reported [3] that mixes with longer fibre lengths resulted in lower slumps and compressive strengths when compared to shorter fibre lengths for the same fibre
volume content. Their results also showed that most of the PVA-FRC mixes had lower compressive strengths than the control concrete. However, this trend was found to reverse after 28 days of curing. The drying shrinkage of PVA-FRC mixes were higher than the control mix, this was more obvious in mixes with longer fibres because of higher mass loss observed in these mixes. It was concluded that the optimum fibre volume fraction was found to be 0.25%.

It was found [4] that crushed bricks as coarse aggregate and steel fibres can be used together to produce light weight concrete that has acceptable properties with density of 1812 kg/m$^3$. The compressive strength of the fibre reinforced light weight concrete increased compared to normal concrete. 0.75% fibre content by volume was recommended as the optimum value of fibre in light weight concrete. The report [4] further stated that the splitting tensile strength, the flexural strength and the static modulus of elasticity significantly increased with the use of steel fibres. It was stated that increasing steel fibre content from 0.75% to 1% by volume of concrete caused decrease in the properties of the concrete such as compressive strength, splitting tensile strength and modulus of elasticity. Lastly, there was an increase in water absorption of lightweight, steel fibre concrete compared to normal concrete. The increase varied between 1.31% and 9.24% depending on the amount of steel fibres.

An experiment [5] carried out on steel fibre as web reinforcement in concrete beams with longitudinal steel reinforcement, showed that by aligning fibres such as carbon, plastic, timber etc., continuously within concrete matrix, the tensile strength of concrete can be improved. The results showed that density and compressive strength of fibre reinforced laterized concrete increased, compared to that of normal concrete. 1.5% fibre content by volume was recommended as the optimum value of fibre in laterized concrete. They indicated that laterized concretes which are fibre reinforced may be used without additional steel links, in minor structures where nominal shear reinforcement is needed.

A research [6] was done on the use of hooked steel fibres instead of stirrups on five beam-column connections subjected to cyclic loading. The results revealed the connections to be more ductile, hence, improving the load carrying capacity, deflection and energy absorption capacities of the connections.

It was reported [7] that in fibre reinforced concrete, if the volume fraction of fibre is low (<1%), there will be no appreciable increase in the compressive and tensile strength. Steel fibre reinforced concrete is very ductile and are recommended particularly for structures which are required to have high fatigue strength capacity for impact, blast and shock loads. Concrete fails suddenly when it is required to sustain deflection beyond the ultimate flexural strength. However, fibre-reinforcement of concrete enables it to sustain considerable loads at deflections in excess of the fracture deflection of plain concrete.

The use of steel swarf in concrete may have lots of benefits, one of which is overcoming some environmental issues that come with production of concrete materials and the conservation of natural resources. The fact that steel swarf is an industrial waste that is locally available contributes to construction cost reduction and infrastructural development. The use of steel swarf in different capacity as a concrete material will make engineering construction more sustainable. Some investigations have been carried out on the use of steel fibres in concrete, but little is known about the deflection and flexural capacity of swarf concrete, an aspect that cannot be over-emphasised in structural capacity considerations.

2.0 EXPERIMENTAL PROCEDURES
The constituents for concrete used for this investigation are Ordinary Portland cement, grade 32.5 as binder, river sand as fine aggregate, crushed granite as coarse aggregate and portable water. All particles passing the BS sieve aperture 2mm but retained on BS sieve 150μm were used as fine aggregate while those particles passing the BS sieve aperture 20mm but retained on BS sieve 2mm were used as coarse aggregate in the study. The steel swarf fibres were obtained from lathe machine of a steel mill in Ogun State, Nigeria, and shown in Figure 1. The steel swarf was cut to an average length of 20mm as shown in Figure 2. The steel swarf fibres used were very short and thin needle-like pieces of metal of about 20mm average length,
thus the mean diameter was 1.2mm and mean aspect ratio of 16.7. Mix proportion of the concrete is 1:2:4 (cement:sand:granite) with 0.55 water/cement ratio.

The percentage of steel swarf was varied from 0% (for control) to 2% volume of the concrete at incremental rate of 0.5%. Fifteen pieces each of 150 x 150 x 150mm cubes, 150x300mm cylinders and 150x150x750mm concrete beams were produced. The concrete elements were demoulded 24hours after casting and stored in a curing tank containing clean water up to 28days age before they were tested for compression, tension and deflection capacity. The setup of the beams for deflection test is as shown in Figure 3.

3.0 RESULTS AND DISCUSSION

3.1 Workability

Workable concrete is one which exhibits very little internal friction between particles or which overcomes the frictional resistance offered by the formwork surface or reinforcements, contained in the concrete with minimum amount of compacting efforts. Table 1 shows the compacting factor ratio and the values of slump.
for each of the concrete mix. The highest slump obtained was 80mm for normal concrete and the lowest
slump was 70mm for 1%, 1.5% and 2% swarf content. Therefore, workable concrete mix had been
achieved; where the specified range is from 50mm to 120mm [8]. The highest compacting factor recorded
was 0.93, for normal concrete, while a constant value of 0.83, (which is the lowest compacting factor in the
mix) was recorded for 1%, 1.5% and 2% swarf content. The workability was good and can be satisfactorily
handled for all the concrete mix. The incorporation of up to 1% swarf content has minimal effect on
workability but a further increase in the swarf content up to 2% had no effect on concrete slump and
compacting factor, as shown in Figure 4.

Table 1: Slump values and degree of workability

| Steel Swarf (%) (By volume) | Slump (mm) | Compacting factor | Type of Slump |
|-----------------------------|------------|-------------------|---------------|
| 0.0                         | 80         | 0.93              | True Slump    |
| 0.5                         | 75         | 0.87              | True Slump    |
| 1.0                         | 70         | 0.83              | True Slump    |
| 1.5                         | 70         | 0.83              | True Slump    |
| 2.0                         | 70         | 0.83              | True Slump    |

It is observed that at 2% swarf content, the slump and the compacting factor was 70mm and 0.83
respectively; these being a slight reduction compared to plain concrete. The reduction in workability of
concrete containing swarf may be due to the adhesion between concrete and steel swarf; the swarf provides
frictional resistance to sliding and interlock behaviour. Moreover, interfacial actions during mixing between
the swarf and the cementitious material in concrete can reduce concrete workability. Lastly, observation of
the fresh state of swarf reinforced concrete shows that addition of the fibre in concrete inhibits bleeding in
fresh concrete, thereby enhancing workability, reducing surface permeability and reducing the formation
and growth of micro cracks in concrete. This is a major factor contributing to concrete durability and
corrosion resistance.

Figure 4: Slump and compacting factor curves
3.2 Effects of swarf on density, compressive and tensile strengths of concrete

Table 2 shows the density, compressive and tensile strength results of the hardened concrete at 28 days with varying swarf percentages (0%, 0.5%, 1%, 1.5% and 2%), while figure 5 shows the compressive and tensile strength strengths. The unreinforced cubes and cylinder failed suddenly after the application of an average stress of 23.41 N/mm² and 2.3 N/mm² respectively, while some cracks were noticed in the swarf reinforced elements before breaking eventually. This confirms the possible improved ductility of the swarf reinforced concrete due to the swarf content. There was no noticeable increase in the compressive strength of swarf concrete with addition of 0.5% swarf, but the strength increase was observed in concrete with 1%, 1.5% and 2% swarf having a compressive strength of 23.81 N/mm², 24.53 N/mm² and 24.73 N/mm² respectively, compared to 23.41 N/mm² of normal unreinforced concrete. The increase in the compressive strength of the swarf concrete as compared to plain concrete was found to be 1.7%, 4.8% and 5.6% with 1%, 1.5% and 2% swarf content respectively.

The increase in the tensile strength compared to that of the plain concrete was found to be 5.2%, 3.9%, 13% and 26% for 0.5%, 1%, 1.5% and 2% swarf content respectively. The increase in the tensile strength may be due to the tensile and ductile property of steel.

The highest value of density obtained was 2636 kg/m³ from the mix containing 2% swarf content while the lowest value of density was 2436 kg/m³ gotten from plain concrete. Thus, as the percentage of swarf content was increased, the density of the concrete increased. The increase in the density of the concrete may be attributed to the density of the steel swarf which is higher than other constituents of concrete.

| Steel Swarf | Weight (kg) | Density (kg/m³) | Compressive strength (N/mm²) | Weight (kg) | Density (kg/m³) | Tensile strength (N/mm²) |
|-------------|-------------|----------------|-----------------------------|-------------|----------------|-------------------------|
| 0%          | 8.28        | 2436           | 23.41                       | 12.65       | 2530           | 2.28                    |
| 0.5%        | 8.43        | 2479           | 23.41                       | 12.51       | 2502           | 2.40                    |
| 1%          | 8.55        | 2516           | 23.81                       | 12.53       | 2506           | 2.37                    |
| 1.5%        | 8.59        | 2527           | 24.53                       | 12.81       | 2562           | 2.61                    |
| 2.0%        | 8.96        | 2636           | 24.73                       | 13.79       | 2641           | 2.90                    |

Figure 5: Compressive strength and tensile strength characteristics with swarf contents
3.3 Regression models for compressive and tensile strength

A simple regression analysis of compressive strength and the swarf content in percentage is shown in Figure 6. The model shows that the percentage of swarf in concrete influences the compressive strength of concrete. It is clear from Figures 6 and 7 that the relationship between the swarf content and compressive strength of concrete follows a polynomial trend with $R^2 = 0.9398$, indicating that the model is reliable and can be used to predict the compressive strength of concrete for a given quantity of swarf in the concrete. The dependency of the compressive strength on swarf content is defined by the regression equation (1)

$$y = 0.2057x^2 + 0.3406x + 23.329$$

where $y$ is the compressive strength (N/mm$^2$) and $x$ is the swarf content (%)

From equation (3.1) the optimum swarf content for compressive strength of concrete was found to be 2%. It can be seen that the trendline forms an asymptote with the curve, indicating the limiting value of the curve. This means beyond 2% swarf content, compressive strength is not likely to increase.

**Figure 6:** Regression curve for compressive strength with varying swarf content
Figure 7: Regression curve for tensile strength with varying swarf content

Regression analysis of tensile strength relative to percentage of swarf content is shown in Figure 7. The model proves that tensile strength is affected by the swarf content. The relationship between the swarf content and tensile strength follows a polynomial with $R^2 = 0.9601$, indicating that the model is reliable and can be used to predict the tensile strength of concrete for a given quantity of swarf in the concrete. The dependency of the tensile strength on swarf content is defined by the regression equation (2)

$$ y = 0.1743x^2 - 0.0586x + 2.3091 $$

where $y$ is the tensile strength (N/mm$^2$) and $x$ is the swarf content (%)

From equation (3.2) the optimum swarf content for tensile strength of concrete was found to be 2%.

3.4 Deflection characteristics of swarf concrete beams

Table 3 and Figure 9 show the values for the failure loads around the centre of the beam and the deflection of beams as observed on the dial guage with different contents of steel swarf. The average load at which the first crack occurred and the ductility of the beams, increased as the percentage fibre content is increased. Samples with 0% fibre content showed only a little deflection capacity before sudden failure. Steel fibres have been reported to distribute localized stresses, thereby reducing damage from impact, flexural fatigue, cracking, spalling and delaminating in hard concrete [1]. This is evident in the results shown in Table 3. The failure of the 0% and 0.5% steel swarf reinforced samples were directly at their centres while the 1%, 1.5% and 2% steel swarf reinforced concrete failed at about 90-100mm away from the centre (towards the point of load application) on either of the sides, as shown in Figure 8. This could be attributed to the unequal distribution and random dispersion of fibre content in the concrete matrix. All the beams failed in flexure. The beams failed at the points of cracks as soon as the cracks appeared.

A maximum deflection value of 0.57mm was observed in beam with 2% steel swarf. This is an increase of 100% compared to that of plain concrete. The flexural strength of swarf reinforced concrete of 2% steel swarf increased by 103% compared to plain concrete. This is in agreement with Faisal et al. [2], who reported a similar trend. The significant increase in the loads at failure for the 1.5% and 2% steel swarf content is an indication that there was good bond between the concrete and the steel swarf, as the surface roughness of the swarf fibres could have contributed to this. The SRC is able to carry further deformation
under increasing load; this is as a result of increased load capacity, flexural strength and flexural toughness. This cannot be unconnected with the high flexural strength of the steel contained in the swarf fibres. It was observed after the failure of the concrete that the swarf fibres did not break; neither did they pull out of the concrete matrix. This ability of the swarf may have resisted the propagation of cracks, separation of the section and improved post cracking ability. This is in agreement with Lidia et al. [9], who opined that the uniform distribution and random arrangement of fibres within the concrete matrix helps it to act efficiently as crack arrestors. The fibre reinforced concrete is able to carry further deformation under increasing load and as a result gives necessary warning before ultimate failure. It can be observed that beams with 0%, 0.5% and 1% swarf content exhibited little or no ductility. It was noticed that as the swarf content increased, the concrete became more ductile and the load carrying capacity increased. The test results show that deflection increased with 1.5% and 2% swarf contents. The increase in deflection was found to be 100% with 1.5% swarf content and 103% with 2.0% swarf content when compared to the plain concrete (Figure 8).

![Figure 8: Failure pattern of beams](image)

| Table 3: load deflection details of the beams |
|---------------------------------------------|
| Load (kN) | 0 | 0.5 | 1.0 | 1.5 | 2.0 |
|-----------|---|-----|-----|-----|-----|
|           | 0 | 0   | 0   | 0   | 0   |
|           | 0 | 0.1 | 0.05| 0.06| 0.06| 0.07|
|           | 9.81| 0.28| 0.26| 0.27| 0.26| 0.26|
|           | 14.7| -   | -   | -   | 0.38| 0.34|
|           | 19.6| -   | -   | -   | 0.56| 0.47|
|           | 24.5| -   | -   | -   | -   | 0.57|
4.0 CONCLUSION AND RECOMMENDATIONS

Based on the test results of the investigation, the following conclusions are drawn:

1. If steel swarf reinforced concrete is well prepared and compacted, the workability is satisfactory. The addition of at least 1.5% steel swarf to concrete improves the compressive strength, tensile strength and density, when compared with normal concrete. Steel swarf reinforced concrete can therefore be used in the area of light reinforced concrete applications such as exterior and interior floors, driveways and parking areas.

2. Maximum load bearing capacity (peak load) and flexural toughness of concrete are significantly increased with the addition of steel swarf by 103% and 150% respectively at 2.0% swarf content compared to plain concrete. The swarf reinforced beams provided better ductility indices of up to 2 times that of plain concrete, with 2% swarf content by volume.
3. Fibre addition improves concrete post-cracking load-carrying capacity. The properties of concrete could be enhanced if it is reinforced with steel swarf fibres of at least 1.5% of the total concrete volume. This research did not consider the effect of the steel swarf’s aspect ratio on the properties of the concrete. It is therefore, recommended that further work should be concentrated on the effect of the steel swarf’s aspect ratio on the concrete properties.

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