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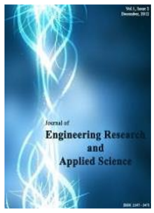

Importance of Surface Morphology of Steel Fibres Used in UHPC Reinforcement

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Abstract

The addition of steel fibres to concrete helps to reduce its inherent brittleness while improving its mechanical properties. Concrete has a low tensile strength which can be improved by the addition of steel fibres. This increase in strength prevents the formation and propagation of cracks, thereby increasing the durability of the concrete. The addition of steel fibres also improves the impact and dynamic strength of concrete. As a result, they are often used in highly stressed structures such as tunnels, bridges, roads and industrial floors.

The aim of this study was to determine the importance of the surface morphology of steel fibres in relation to concrete reinforcement, and in particular to investigate its effect on the production process of Ultra High Performance Concretes (UHPC). It was found that fibres with surface scratches exhibited increased adhesion and agglomeration, resulting in uneven distribution during the production of UHPC. The use of scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) revealed that surface roughness causes agglomeration due to the formation of static electricity and subsequent attractive forces.

Keywords: *Steel fibre, UHPC, Agglomeration, SEM-EDS*

1. Introduction

Concrete is currently the most widely used construction material, having gained a dominant position in modern infrastructure due to several key advantages. Its exceptional durability and the widespread availability of its raw materials (cement, water, and aggregates) have made it the preferred choice for many construction applications. Its versatility and reliability make it indispensable in a wide range of structures, including bridges, dams, skyscrapers, roads, and tunnels [1].

Concrete is a cement-based material with suboptimal fatigue, abrasion, tensile strength and toughness properties and a brittle structure [2]. However, the technical properties of concrete can be significantly improved by the incorporation of various additives [3], [4]. By modifying the composition, the inherent weaknesses of concrete can be identified and systematically reinforced, resulting in a more robust and durable material. The addition of pozzolanic materials, such as fly ash or silica fume, improves the workability of concrete, reduces its permeability and increases its resistance to chemical attack, thereby prolonging the life of the structure [5]. In addition, the addition of steel, glass or synthetic fibres with a specific length/diameter ratio to concrete improves its inherent brittleness by increasing its tensile strength and crack resistance [6],[7]. The use of fibre reinforced concretes is also economically advantageous due to the reduction in installation time, which is a significant benefit for secondary precast concrete elements used in civil and industrial buildings or infrastructure projects. The addition of fibres to concrete provides structural integrity, reducing the possibility of concrete cracking or water ingress. Fibre-reinforced concretes are classified into several categories, including GFRC, UHPC, plastic-based polypropylene fibre concrete, carbon fibre concrete and steel fibre concrete [8].

UHPCs are an advanced class of construction materials characterized by their exceptional mechanical properties [9]. These include extremely high compressive strength, remarkable flexural and tensile strengths, and superior ductility compared to conventional concrete. One of the primary characteristics of ultra-high-performance concrete (UHPC) is its markedly low water-to-binder ratio. This significantly reduces the pore volume and size

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within the cementitious matrix, resulting in a highly compact microstructure. This densification contributes to the enhanced mechanical performance and durability of UHPC [10]. In addition to its high strength, UHPC is highly resistant to environmental degradation and other forms of material deterioration, making it an excellent choice for various structural applications. The integration of substantial quantities of steel fibres has been widely recognized as a critical factor in enhancing both the strength and toughness of UHPC [11]. These fibres play a vital role in bridging micro-cracks within the matrix, thereby improving crack resistance and load transfer capabilities. This reinforcement mechanism not only increases the overall mechanical strength of the material but also significantly boosts its toughness, enabling UHPC to sustain higher loads and exhibit superior energy absorption before failure. Therefore, the strategic use of steel fibres is fundamental to realizing the full potential of UHPC in structural applications [12].

Steel fibre reinforced concrete is a composite material obtained by homogeneously adding steel fibres to conventional concrete [13]. The addition of these small fibres, typically randomly distributed throughout the concrete mix, has been shown to improve the structural properties of the resulting concrete [14]. Steel fibre reinforced concretes are typically preferred in applications where durability and strength are paramount, including industrial floors, pavements, tunnel linings and structural elements subject to dynamic loading. Steel fibres bridge cracks, control their propagation and extend the overall life of the concrete [15]. The main factors influencing the strength of steel fibre reinforced concrete are the type, geometry, volume fraction, surface properties, orientation and distribution of the steel fibres in the concrete matrix. It is also of paramount importance that the fibres are homogeneously distributed throughout the concrete and that this distribution is maintained after the mixing process and throughout the life of the concrete.

This study investigates the issue of 'agglomeration' of steel fibres used to improve the mechanical properties of concrete. The morphologies of the steel fibres, classified as either suitable or problematic, were analysed by scanning electron microscopy (SEM), while their surface compositions were characterized by energy dispersive X-ray spectroscopy (EDS). The correlation between surface morphological changes and agglomeration was thoroughly investigated.

2. Materials and Method

The composition of the 316L stainless steel fibre used in the study: Iron (Fe): 62-70%, Chromium (Cr): 16-18%, Nickel (Ni): 10-14%, Molybdenum (Mo): 2-3% and carbon (C): Maximum 0.03%. Scanning Electron Microscopy (SEM) is a powerful imaging tool that uses focused electron beams to produce detailed, high-resolution images of the surface of a sample. In contrast, energy dispersive X-ray spectroscopy (EDS) identifies the X-rays emitted from a sample as a result of the interaction between the electron beam and the material under investigation. This allows the identification of the elemental composition based on the characteristic energies of the elements. In this study, problematic and suitable fibres were attached to aluminum using double-sided carbon tape. The surface morphology of the fibres was examined using a Quanta FEG 250 model (FEI, Netherlands) SEM-EDS instrument with an accelerating voltage of 20 keV.

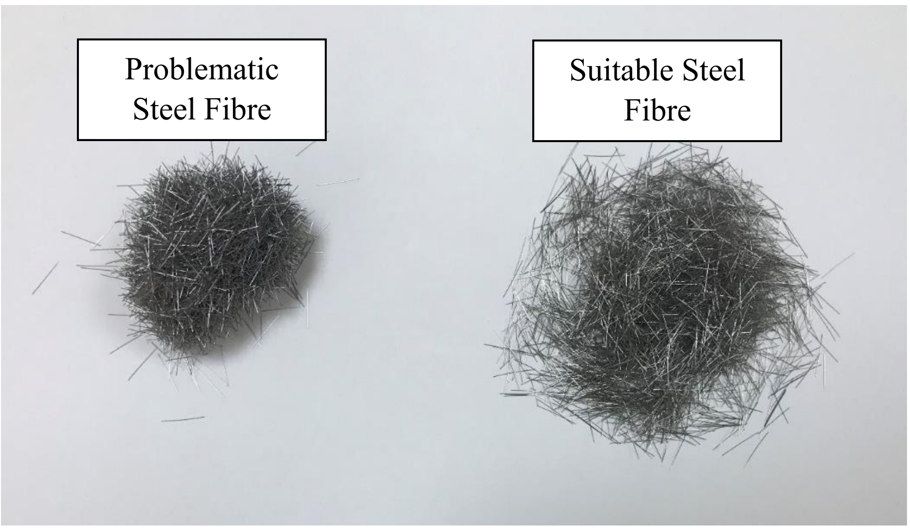

Figure 1. Images of problematic and suitable steel fibres

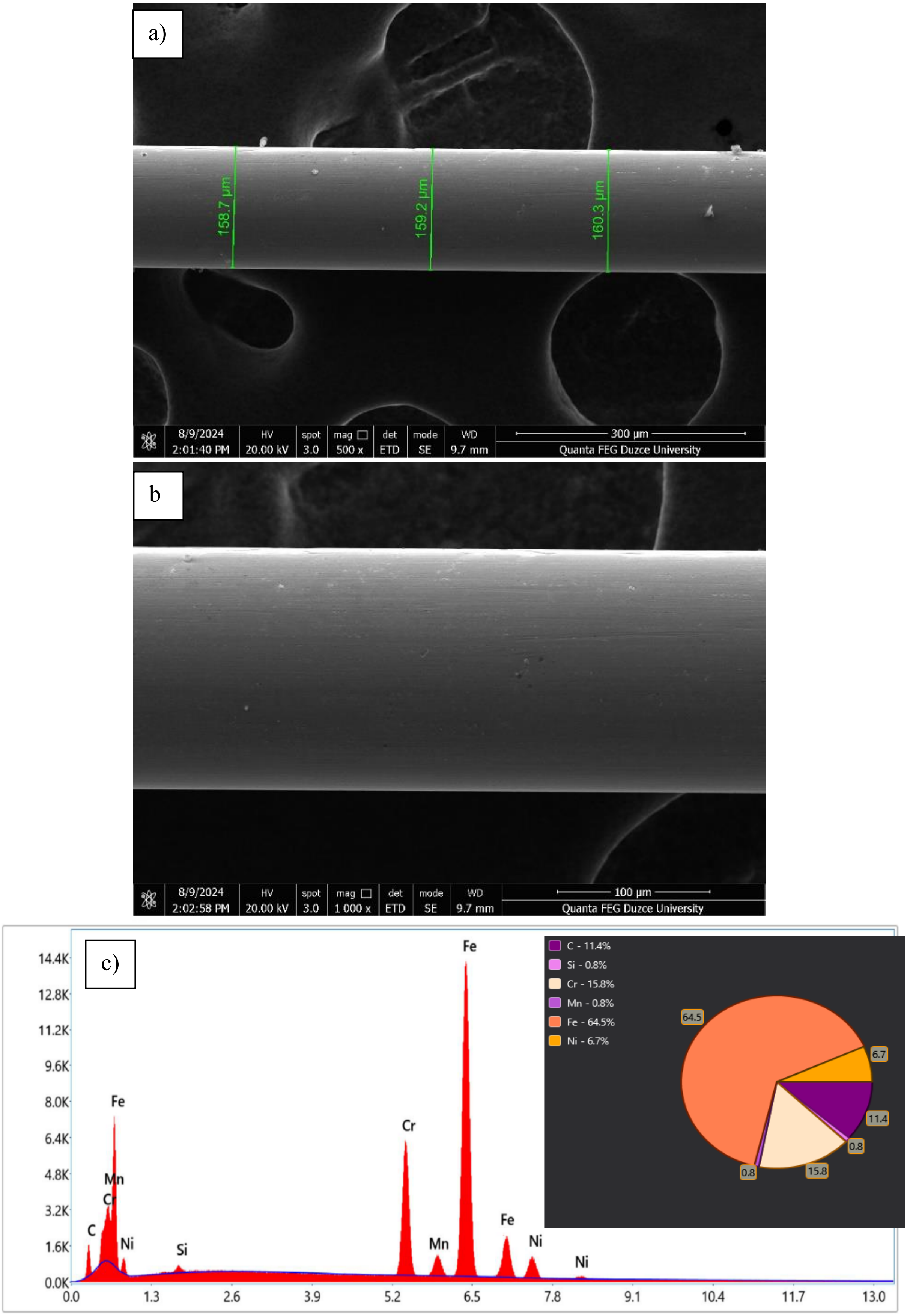

Figure 2. SEM-EDS analysis results of suitable steel fibres; a) 500x, b) 1000x, c) EDS spectra

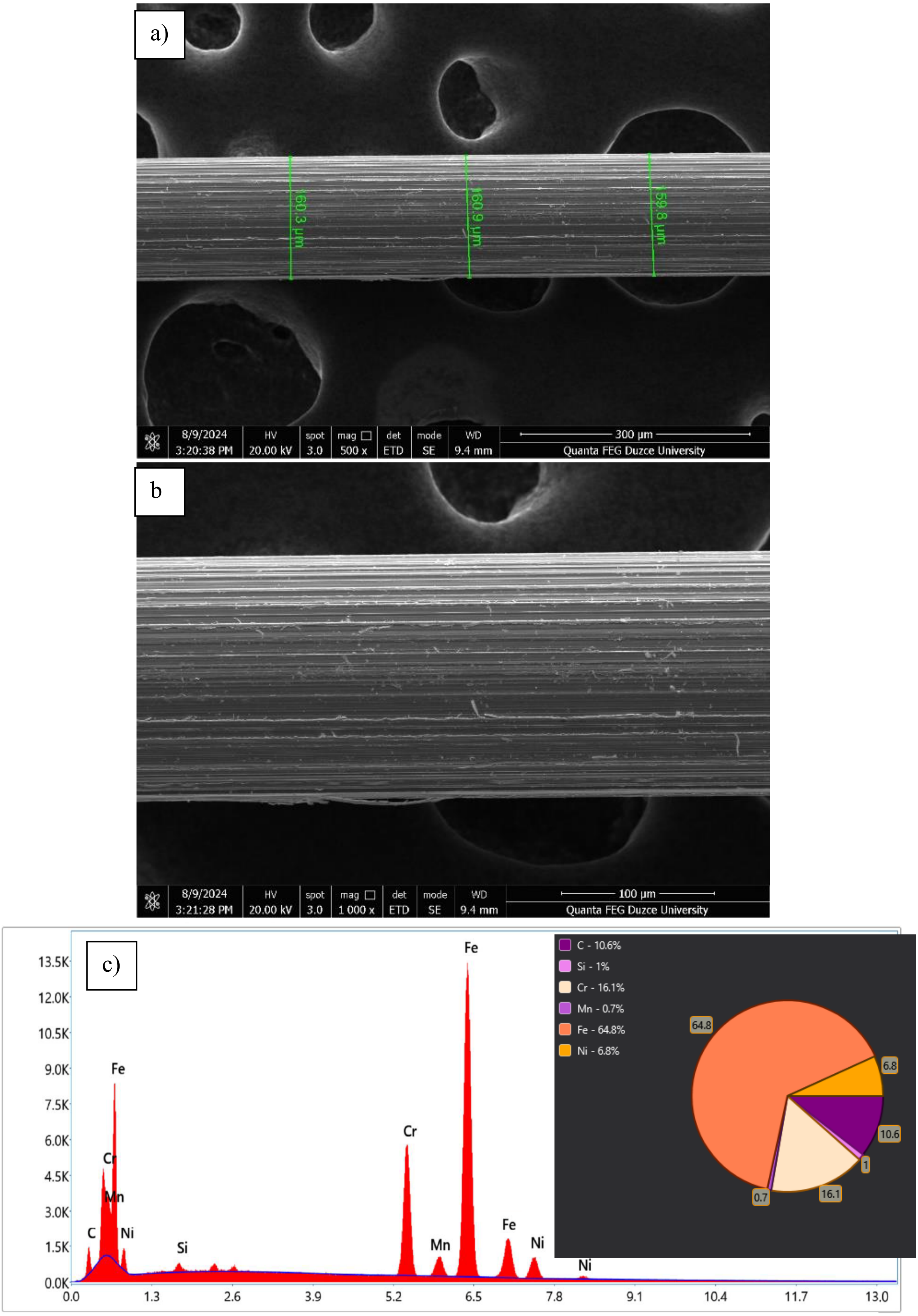

Figure 3. SEM-EDS analysis results of problematic steel fibres; a) 500x, b) 1000x, c) EDS spectra

3. Results and Discussion

A digital image of the problematic and suitable steel fibres used as concrete reinforcing elements is shown in Figure 1.

The presence of a balling problem in the problematic steel fibres is shown in Figure 1. The SEM-EDS images of the acceptable and problematic fibres used to determine the balling problem are shown in Figures 2 and 3.

An analysis of Figure 2 and Figure 3 shows that the compositional ratios of the two fibres are relatively similar in the graphs obtained by EDS analysis. This suggests that the suitable and problematic fibres are comparable in terms of their chemical composition. However, the SEM images revealed the presence of surface scratches on the problematic steel fibre. Steel fibres with rough surfaces have several disadvantages, including increased susceptibility to corrosion, reduced machinability, difficulties in surface coating and a tendency to balling. Previous studies in the literature have shown that deep and wide scratches can significantly increase surface roughness, allowing greater adhesion between metal surfaces. Rough surfaces can result in an increased number of metallic contact points, thereby increasing the risk of friction and adhesion [15]. It is hypothesized that the balling problem is caused by the presence of scratches on the metal surface.

4. Conclusion

In this study, the effect of steel fibre surface morphology on the GFRC production process was investigated for the first time using SEM and EDS techniques. SEM-EDS analyses revealed that, while the chemical compositions of the suitable and problematic steel fibres were comparable, the problematic fibres exhibited pronounced surface scratches. These scratches increase surface roughness, leading to fibre balling and hindering their homogeneous distribution within the concrete matrix. The results suggest that fibre surface smoothness is a critical factor influencing material performance and durability in GFRC production and demonstrate that even the smallest issues in the production of stainless-steel fibres used in concrete can lead to significant production challenges. Future research should further investigate the effect of rough fibres on corrosion resistance.

Acknowledgments

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