The object of this study is to combine the properties of Mn and the advantages of Fe-Cr-C to improve biomaterial compatible characteristics. Three alloys of Fe-Cr-C with compositions of 12 wt. % Mn, 16 wt. % Mn, and 20 wt. % Mn, were investigated. Microstructural analysis was carried out using a scanning electron microscope (SEM), and a Vickers hardness test kit was used to evaluate the hardness. The pin-on-disc method was used for the dry slide wear test, and the corrosion test was carried out using the three-electrode cell polarization method. The hardness value of Fe-Cr-C alloy increased by 28.7 % with the increase of Mn content from 12 wt. % (231.8 VHN) to 20 wt. % (298.4 VHN). The tensile strength value increased by 30.3 % with an increase in Mn content from 12 wt. % (522.69 MPa) to 20 wt. % (680.89 MPa), while the strain value decreased by 30.9 %. However, impact toughness did somewhat decline, from 0.213 J/mm^2 at 12 wt. % Mn to 0.169 J/mm^2 at 20 wt. % Mn. The wear rate results for Fe-Cr-C 20 wt. % Mn 0.000156 mm^3/kg. show a reduction of more than 15 wt. % when compared to Fe-Cr-C 12 wt. % Mn because of an increase in the hard-intermetallic area. Additionally, corrosion resistance improved significantly, with the corrosion rate decreasing from 0.005814 mm/yr at 12 wt. % Mn to 0.001780 mm/yr at 20 wt. % Mn, demonstrating that higher Mn content reduces material degradation in corrosive environments. Based on the experimental results, Fe-Cr-C 20 wt % Mn alloy has the highest mechanical and corrosion resistance of the three types of alloys. Fe-Cr-C with high Mn alloys are promising candidates for application as biomaterials for bone implants by optimizing the Mn content and corrosion resistance

Keywords: Fe-Cr-C alloy, biomaterials, mechanical properties, corrosion resistance, Mn content, orthopedic implants

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DEVELOPMENT OF FE-CR-C ALLOYS WITH HIGH MN CONTENT FOR BONE IMPLANT

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1. Introduction

Biomaterials are essential to modern medicine, especially in the areas of regenerative medicine, dentistry, and orthopedics. Their mechanical characteristics, biocompatibility, and tissue integration capacities are the main factors that influence their choice and application. To ensure endurance under physiological stresses without failure or unfavorable reactions, the ideal biomaterial must have mechanical qualities such as elasticity, ductility, toughness, and strength that closely resemble those of human tissues, particularly bone [1]. The interplay of biomaterials and the host immune system is critical to the effectiveness of implants. Biomaterials will always cause a foreign body response (FBR) after implantation, which can result in tissue remodeling and inflammation. Surface features like topography and chemical composition have a big impact on how cells react, which can change how much inflammation there is and how well the surface integrates with the host tissue [2].

A key requirement for biomaterials is biocompatibility, which establishes the material's capacity to blend in with biological tissues while reducing immunological responses. Titanium and its alloys are widely employed among metallic biomaterials because of their exceptional mechanical strength and resistance to corrosion. However, it has been noted that certain people are hypersensitive to metals, including titanium, which means that material selection should be done carefully [3]. The way biomaterials degrade is another important aspect of their performance. In order to minimize the need for additional removal surgeries, biodegradable materials-like polylactic acid and polyglycolic acid-are made to progressively decompose and be replaced by natural tissues. Premature degradation, however, can result in implant failure, hence it's crucial to regulate the rate to meet tissue regeneration [4].

Since its inception in the 1930s, 316L stainless steel has gained popularity as a biomaterial for orthopedic implants and other medical devices because of its mechanical qualities, biocompatibility, and affordability. Because of the alloy's superior corrosion resistance and combination of molybdenum, nickel, and chromium, it can be implanted for an extended period of time [5]. Notwithstanding these benefits, stainless steel has its drawbacks. Its vulnerability to biofilm formation and bacterial adhesion increases the risk of infection, which is a major surgical complication. It has been discovered that the chemistry and topography of stainless steel's surface affect bacterial colonization, indicating that surface alterations may lower the risk of infection. Furthermore, certain individuals may experience allergic reactions to nickel, which has prompted the creation of nickel-free substitutes [6].

Because manganese (Mn) improves the mechanical and biological properties of emerging materials, including Fe-Cr-Mn alloys, these materials are being considered as attractive options for biomaterials. These alloys have the potential to be stronger, more ductile, and resistant to wear, especially when designed as high-entropy alloys (HEAs), which makes them appropriate for demanding applications like dental prosthesis and orthopedic implants. Chromium and manganese are two of the alloying elements that work to minimize metal ion release, which in turn reduces the risk of toxicity and unfavorable immunological reactions [7].

Therefore, research devoted to the development of new biomaterials with enhanced mechanical properties and biocompatibility is essential and relevant to the possibility of Fe-Cr-Mn alloys serving as a good substitute for 316L stainless steel offers a bright future for biomedical applications.

2. Literature review and problem statement

Stainless steel, particularly the austenitic grade AISI 316L, has established itself as a prominent material in the field of biomaterials, particularly for medical implants. Its widespread application can be attributed to a combination of favorable mechanical properties, excellent corrosion resistance, and biocompatibility, making it suitable for various orthopedic and dental applications. The mechanical strength and fatigue resistance of stainless steel are critical for load-bearing implants, such as bone plates, screws, and joint replacements, where the material must withstand significant stress and strain during normal physiological activities [8].

There were unresolved issues related to the corrosion which could affecting the long-term stability of the implant. As mentioned on the paper, corrosion can lead to material degradation and subsequent failure of the implant. The corrosion resistance of stainless steel is particularly noteworthy, as it forms a passive oxide layer that protects the underlying metal from aggressive bodily fluids. A way to overcome this difficulty can be through various surface modifications, such as nitriding and coating with biocompatible materials like hydroxyapatite, which can improve both the corrosion resistance and the bioactivity of the implants [9].

In addition to its mechanical and corrosion properties, stainless steel's biocompatibility is a crucial factor in its selection for biomedical applications. The material's ability to integrate with biological tissues without eliciting significant adverse reactions is vital for the success of implants. Studies have shown that austenitic stainless steels, particularly 316L, exhibit good biocompatibility, making them suitable for use in various implants, including those used in orthopedic and dental applications [10]. However, concerns regarding nickel allergies have prompted research into nickel-free alternatives, which maintain similar mechanical properties while reducing the risk of allergic reactions. Despite its advantages, stainless steel is not without limitations. The susceptibility of austenitic stainless steels to localized corrosion, such as pitting and crevice corrosion, particularly in saline environments, poses challenges for long-term implant performance [7]. Research efforts are ongoing to develop surface treatments and coatings that can mitigate these issues, enhancing the overall durability and reliability of stainless-steel implants [11].

The application of Fe-Cr-Mn alloys in the field of biomaterials has garnered significant attention due to their unique mechanical properties, corrosion resistance, and biocompatibility. The extraction and processing of these metals can lead to environmental concerns, particularly regarding chromium, which is known for its toxicity in certain forms. However, advancements in alloy design and processing techniques aim to minimize these impacts while maximizing the performance of the materials [12]. All this suggests that it is advisable to conduct a study on the development of sustainable practices in the production of Fe-Cr-Mn alloys.

High-entropy alloys, such as those containing Fe, Cr, and Mn, have been shown to possess superior mechanical properties compared to traditional alloys. For instance, the addition of Mn has been reported to stabilize the face-centered cubic (FCC) structure, enhancing the ductility and toughness of the alloy [13]. This structural stability is crucial for applications where mechanical integrity is paramount, such as in load-bearing implants. Furthermore, manganese plays a critical role in enhancing the structural integrity and performance of these alloys. One of the primary advantages of incorporating Mn into Fe-Cr alloys is the enhancement of mechanical properties. Manganese has been shown to stabilize the austenitic phase in iron-based alloys, which contributes to improved ductility and toughness [10]. This is particularly important for biomaterials, as implants must withstand significant mechanical loads without fracturing. The addition of Mn can also influence the dislocation dynamics within the alloy, leading to a reduction in the energy of the antiphase boundary and an increase in ductility [9]. This improvement in ductility is crucial for applications where the material must undergo deformation during service without catastrophic failure.

The biocompatibility of Fe-Cr-Mn alloys is another critical factor that influences their application in biomaterials. Studies have demonstrated that these alloys can support cell adhesion and proliferation, which are vital for successful integration with biological tissues. The corrosion resistance provided by Cr not only enhances the longevity of the implants but also minimizes the release of metal ions into the body, reducing the risk of adverse biological reactions. Research has shown that Fe-Mn alloys can exhibit favorable interactions with biological tissues, promoting cell adhesion and proliferation [14]. This is particularly relevant for temporary implants, where the material must integrate with surrounding tissues before being resorbed by the body.

The microstructural characteristics of Fe-Cr-Mn alloys are also influenced by the addition of manganese. Manganese can affect the phase stability and microstructural evolution during processing, which in turn impacts the mechanical properties of the final product. For instance, the solidification behavior of these alloys can be modified by adjusting the Mn content, leading to variations in grain size and phase distribution that are critical for achieving desired mechanical properties. Understanding the thermodynamics of phase formation in these alloys is essential for optimizing their processing conditions and ensuring consistent performance in biomedical applications [15].

Moreover, the corrosion resistance of Fe-Cr-Mn alloys is significantly enhanced by the presence of manganese. Studies have indicated that Mn contributes to the formation of a protective oxide layer on the alloy surface, which is essential for preventing corrosion in biological environments [9]. The presence of chromium (Cr) further complements this effect, as it is well-known for its ability to form stable passive films that protect against corrosion [11]. The combination of Mn and Cr in these alloys not only improves their resistance to localized corrosion but also enhances their overall durability in physiological conditions, where exposure to bodily fluids can lead to degradation of less resistant materials.

In addition to their mechanical and corrosion properties, the biocompatibility of Fe-Cr-Mn alloys is influenced by their surface characteristics. The surface roughness and chemical composition can affect protein adsorption and cell attachment, which are critical for the integration of implants with surrounding tissues [12]. Techniques such as surface modification and coating can be employed to enhance the biocompatibility of these alloys, promoting better interaction with biological systems [13]. Furthermore, the ability to tailor the surface properties of Fe-Cr-Mn alloys through various treatments allows for the customization of implants to meet specific clinical requirements.

All this suggests that is advisable to conduct study on Fe-Cr-Mn with the variation of manganese. This alloy provides significant advantages for their application as biomaterials.

3. The aim and objectives of the study

The aim of the study is to develop Fe-Cr-C alloy as a bone implant biomaterial with variations in weight % Mn between 12, 16, and 20.

To achieve the aim, the following objectives were set:

– investigate the microstructure of the Fe-Cr-C alloy;

– examine the mechanical properties of Fe-Cr-C alloy;

– explore the corrosion resistance.

4. Materials and methods

The object of this study is to combine the properties of Mn and the advantages of Fe-Cr-C to improve biomaterial compatible characteristic.

The main hypothesis of the study is Fe-Cr-C alloy with high Mn content can be used as a non-toxic bone implant and in terms of mechanical properties does not interfere with the healing process. The assumptions made in this study are the perfect melting process, homogeneous materials and no casting defects occur. Simplification adopted in the study is the solution used in the corrosion test using 0.9 % NaCl.

The research was conducted by an 80 kg high-frequency induction chamber that was used for the smelting of the Fe-Cr-Mn alloy. The study's raw materials included Fe-Cr, Fe-Mn, Fe-C, and scrap mild steel. The Fe-Cr-Mn alloy casting is 30×30×200 mm in size, formed like an ingot. To investigate the alloys' chemical compositions, an inductively coupled plasma optical spectrometer was employed. The chemical compositions of the tested specimens are displayed in Table 1. Furthermore, the annealing process is carried out on Fe-Cr-Mn alloy ingots at 900 °C for 1 hour using a muffle furnace to homogenize the alloy structure.

The chemical composition, microstructures, hardness, tensile, impact, and corrosion were among the parameters tested. Based on the ASTM E2209 standard test, the composition test was performed using a Baird FSQ Foundry Spectrovac Spectrometer. The microstructures were examined using a JEOL type JSM.6360-LAEDX (JED 2200 series) Scanning Electron Microscope-Energy Dispersive X-Ray System. The Schmierplan/Libriction plan LA-H-250 RC 16-02/Hardness Tester DIA Testory micro-Vickers method was used to conduct the mechanical testing. The procedure for the Vickers hardness test was derived from ASTM E384. Tensile testing was carried out using a TN 20 MD Controlab tensile testing machine, based on ASTM E8 standards, while impact testing was carried out using the Charphy method based on ASTM E23 07 A standards. Lastly, a CMS 100 Gamry Instrument corrosion polarization test was run in order to measure the corrosion rate of Fe-Cr-C alloy in 0.9 % NaCl. The polarization potential was determined using the ASTM G5 standard.

The chemical composition of the Fe-Cr-C presented in Table 1.

In order to achieve the research goal of figuring out how raising the Mn levels affects different examined features, the levels of Cr, C, and Mn were adjusted during the alloy-making process. As the Mn content rose, the Fe content fell in the interim.

Table 1

The chemical composition of Fe-Cr-C alloy with variations in weight % Mn

Elements / %wt.	Fe	Cr	Mn	C	Si	P	Ni	Mo
12	66.8	18.50	12.72	0.70	0.96	0.09	0.21	0.02
16	43.45	18.24	16.04	0.75	1.24	0.07	0.19	0.02
20	58.84	18.05	20.69	0.72	1.43	0.09	0.16	0.02

5. Results of Fe-Cr-C with high Mn characteristics

5. 1. Results of the microstructure of Fe-Cr-C alloys

5. 1. 1. Results of the scanning electron microscope of Fe-Cr-C alloys

Fig. 1 shows the microstructure result of the Fe-Cr-C with wt. % Mn between 12(*a*), 16 (*b*) and 20 (*c*).

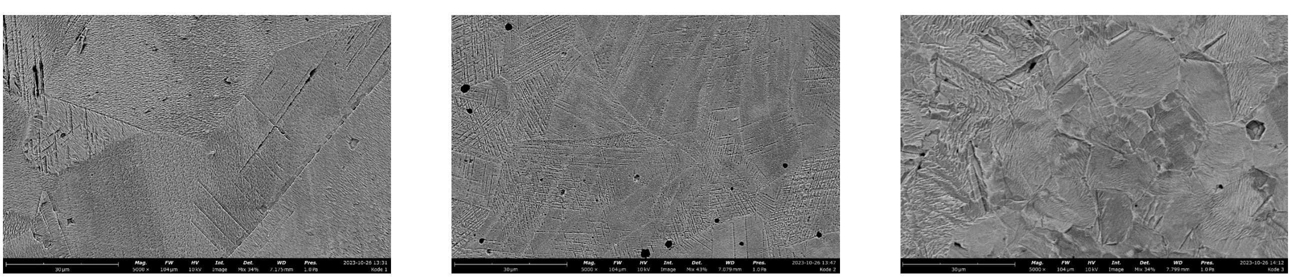
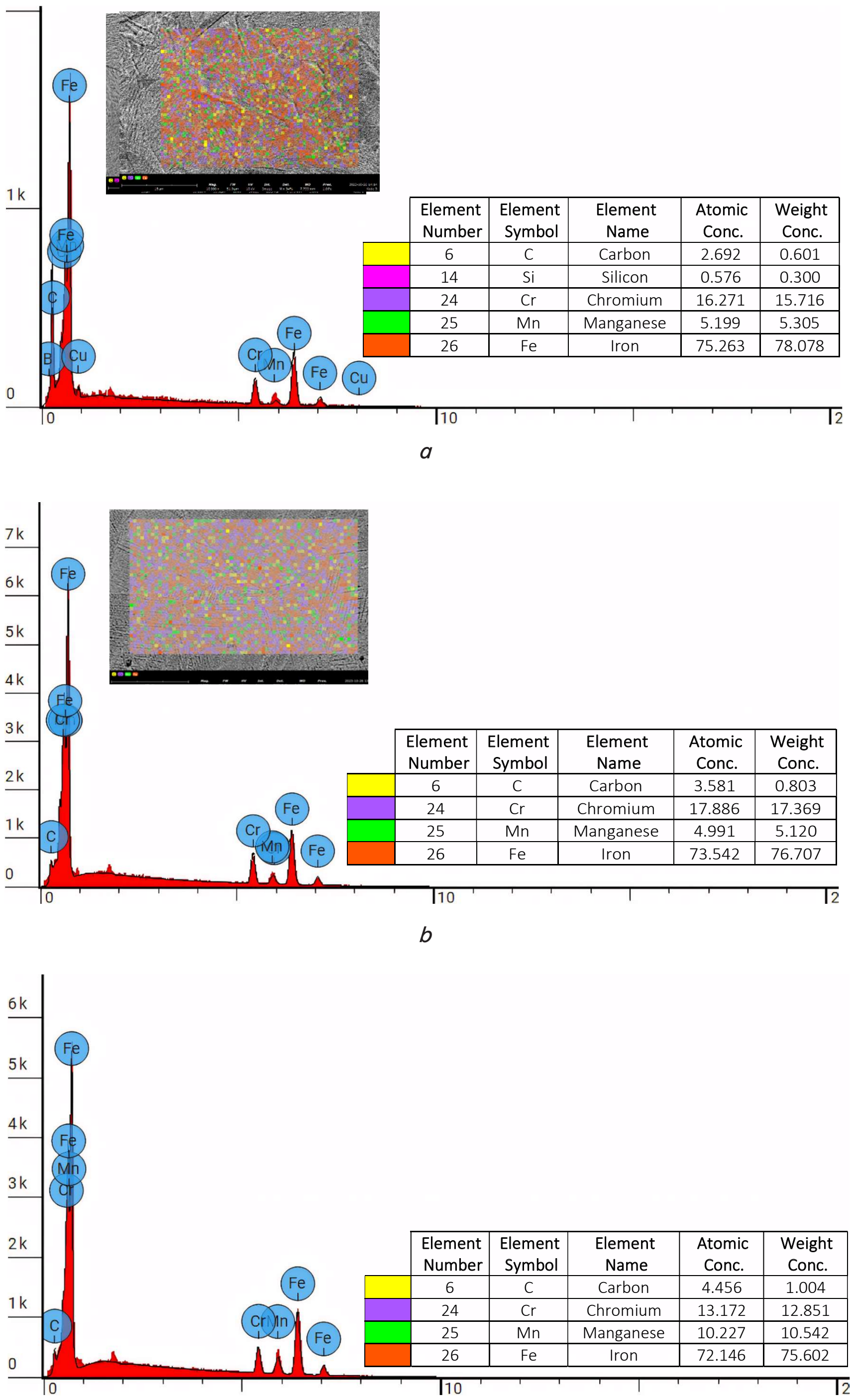


Fig. 1. The Microstructure of Fe-Cr-C with variations weight % of Mn: *a* – 12 wt. % Mn; *b* – 16 wt. % Mn; *c* – 20 wt. % Mn

Microstructure test results (Fig. 1) show that Fe-Cr-C alloys with all three weight % of Mn have a perfect austenite structure. Each composition shows variations in austenite grain orientation, where the higher the Mn content, the finer the austenite grain size. From the three Fe-Cr-Mn compositions, it can be seen that increasing the Mn content from 12 % to 20 % contributes to the refinement of the austenite structure. The grains become finer with increasing Mn content, indicating an increase in austenite stability. Alloys with higher Mn content (20 %) tend to have better mechanical properties, such as higher strength, ductility and wear resistance, due to smaller grain size and more uniform distribution [16]. As shown in the ternary diagram Fe-Cr-Mn, the perfect austenite structure is formed at Cr levels of about 14 to 18 % by weight and Mn 9 to 10 % by weight. In cast objects, the shape and grain size of austenite are greatly influenced by the type of mold used. In sand molds, factors such as size, molding sand grain distribution, and mold permeability greatly affect the shape and grain size of the resulting alloy [14].

5. 1. 2. Results of the energy dispersive spectroscopy of Fe-Cr-C alloys

Fig. 2 shows the SEM-EDS micrograph result of the Fe-Cr-C with wt. % Mn between 12 (*a*), 16 (*b*) and 20 (*c*).



a

	Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
(yellow)	6	C	Carbon	2.692	0.601
(magenta)	14	Si	Silicon	0.576	0.300
(purple)	24	Cr	Chromium	16.271	15.716
(green)	25	Mn	Manganese	5.199	5.305
(orange)	26	Fe	Iron	75.263	78.078

b

	Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
(yellow)	6	C	Carbon	3.581	0.803
(purple)	24	Cr	Chromium	17.886	17.369
(green)	25	Mn	Manganese	4.991	5.120
(orange)	26	Fe	Iron	73.542	76.707

c

	Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
(yellow)	6	C	Carbon	4.456	1.004
(purple)	24	Cr	Chromium	13.172	12.851
(green)	25	Mn	Manganese	10.227	10.542
(orange)	26	Fe	Iron	72.146	75.602

Fig. 2. The SEM-EDS micrograph of Fe-Cr-C with variations weight % of Mn: *a* – 12 wt. % Mn; *b* – 16 wt. % Mn; c – 20 wt. % Mn

The EDS test results show that the Cr and Mn content at the taken spot differs from the macro composition test results, indicating the possibility of phase formation or intermetallic compounds within the varied alloy. The elements Cr and Mn occupy substitutional positions, replacing one or more Fe atoms, depending on the phase formed, in the face-centered cubic system. Mapping results show that the distribution of Cr, Mn, and C elements appears homogeneous.

5. 2. Results of the mechanical properties of Fe-Cr-C alloys

5. 2. 1. Results of the hardness of Fe-Cr-C alloys

The hardness distribution of Fe-Cr-Mn alloy with various weight % of Mn is presented in Fig. 3.

Fig. 3 shows that the Fe-Cr-C alloy has hardness values of 231.8 VHN, 257.9 VHN and 298.4 VHN at 12 %, 16 % and 20 % Mn by weight, respectively. These values indicate that the Fe-Cr-C alloy in this research has a hardness value above that of SS 316 L (230.7 VHN). This is due to the role of Mn in Fe-Cr-Mn alloys which has a significant effect on increasing the hardness value. The higher the Mn content the more the hardness increases, because Mn plays a role in improving mechanical properties significantly [17]. Mn is known as an alloying element that can increase hardness and strength in steel and iron-based alloys. The addition of Mn strengthens the material by a solid solution hardening mechanism.

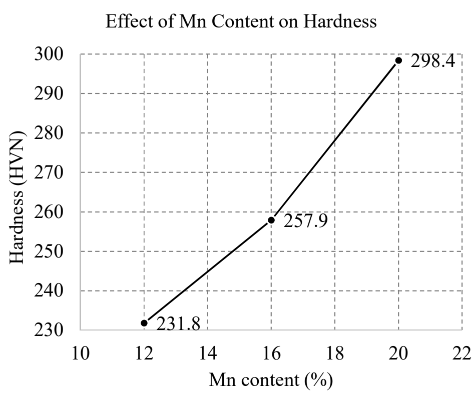


Fig. 3. The hardness distribution of Fe-Cr-C with variations in weight % Mn

5. 2. 2. Results of the tensile of Fe-Cr-C alloys

The result of tensile test of Fe-Cr-Mn alloy with various weight % of Mn is presented in Fig. 4.

In Fig 4, it can be seen that as the Mn content increases, the average tensile stress of the material increases significantly. At 12 % Mn content, the tensile stress is 522.69 MPa, while at 20 % Mn content, the tensile stress reaches 680.89 MPa. This increase in tensile strength indicates that the addition of Mn serves as a reinforcement in the alloy, increasing the material's ability to withstand tensile loads without undergoing permanent deformation. Mn acts as a solid solution hardener, where its presence in the Fe-Cr-Mn matrix increases stiffness and resistance to dislocations [18]. From 12 % Mn to 16 %, there was an increase in stress 12,5 %, while from 16 % to 20 %, the stress increased even more, by 15,5 %. This shows the increasing effect of adding Mn in strengthening the material structure as its content is increased. In contrast, the average strain decreased as the Mn content increased. At 12 % Mn content, the average strain was 55 %, which indicates the flexibility or ability of the material to stretch without fracture. However, at 20 % Mn content, the strain declined to 38 %. This indicates that as the strength of the material increases, the alloy becomes less ductile. Alloys with higher Mn content are able to withstand greater loads but at the expense of the ability to stretch before fracture [14].

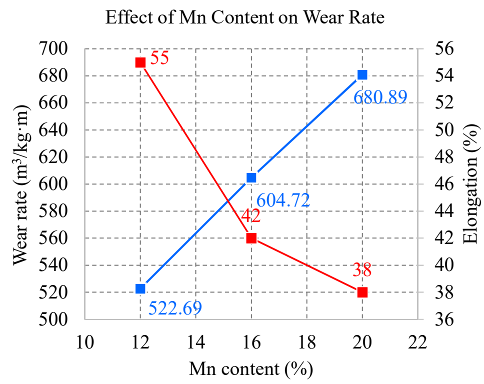


Fig. 4. The tensile strength of Fe-Cr-Mn with variations in weight % Mn

5. 2. 3. Results of the impact of Fe-Cr-C alloys

The result of impact test of Fe-Cr-Mn alloy with various weight % of Mn is presented in Fig. 5.

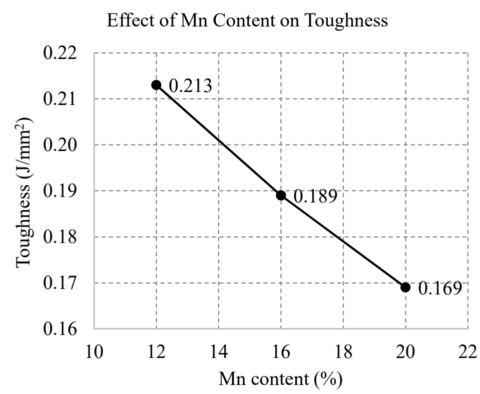


Fig. 5. The impact strength of Fe-Cr-Mn with variations in weight % Mn

Fig. 5 shows that the impact value decreases as the Mn content in the alloy increases. At 12 % Mn content, the impact value is 0.213 J/mm^2, while at 20 % Mn content, the impact value decline to 0.169 J/mm^2. This shows that as the Mn content increases, the alloy becomes more brittle, which means that the alloy is less able to absorb energy before fracture. Manganese (Mn) is known to increase the tensile strength of alloys through solid solution hardening, as discussed in the previous analysis. However, this increase in strength is often followed by a decrease in the toughness of the material. This occurs because the higher the Mn content, the more resistance is generated for the movement of dislocations within the crystal, which makes the material stiffer yet easier to fracture under stress. This decrease in toughness is reflected by the decrease in impact value at higher Mn levels [12].

5. 2. 4. Results of the wear of Fe-Cr-C alloys

Table 2 and Fig. 6 show the wear rate of Fe-Cr-Mn alloy with various weight % of Mn. The wear rate decreases as Mn content increases, suggesting that higher Mn levels enhance the alloy's resistance to wear.

Fig. 6 shows that as the Mn content increases from 12 % to 20 %, the wear value of the alloy decreases consistently.

At 12 % Mn content, the wear value was 0.000184 mm^3/kg, while at 20 % Mn content, the wear value decreased to 0.000156 mm^3/kg. This decrease indicates that the higher the Mn content, the more resistant the alloy becomes to wear. This can be attributed to the increase in hardness and strength of the material due to the addition of Mn, which reduces the rate of scraping or flaking of the material during the friction test.

Table 2

The wear rate of Fe-Cr-Mn with variations in weight % Mn

wt. % Mn	12	16	18
Wear rate (m^3/kg.m)	0.000184	0.000175	0.000156

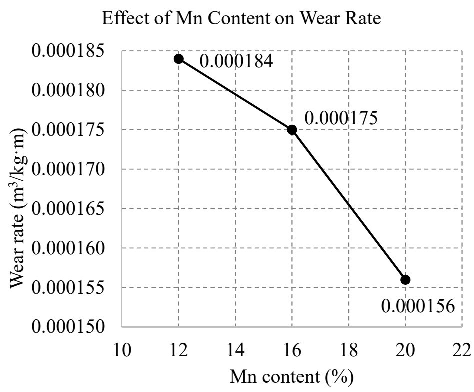


Fig. 6. The wear rate of Fe-Cr-Mn with variations in weight % Mn

5. 3. Results of the corrosion of the Fe-Cr-C alloys

Table 3 shows the corrosion rate of Fe-Cr-Mn alloy with various weight % of Mn. The corrosion rate decreases as the Mn content increases, indicating that higher Mn levels enhance the corrosion resistance of the material.

Fig. 7 shows that increasing the manganese (Mn) content in the alloy leads to a significant decrease in the corrosion rate. At 12 % Mn content, the alloy has a corrosion rate of 0.005814 mm/year, while at 20 % Mn content, the corrosion rate declines to 0.001780 mm/year. This trend shows that the higher the Mn content in the alloy, the more resistant the material is to corrosion. The lowest corrosion rate value is categorized as outstanding [19]. This phenomenon is related to the role of Mn in improving the stability and corrosion resistance of the material.

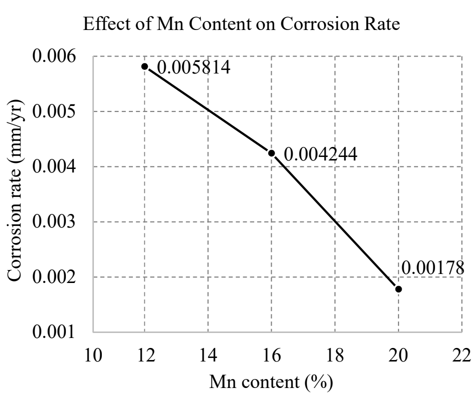


Fig. 7. The corrosion rate of Fe-Cr-Mn with variations in weight % Mn

Table 3

The corrosion rate of Fe-Cr-Mn with variations in weight % Mn

wt. % Mn	12	16	18
Corrosion rate (mm/yr)	0.005814	0.004244	0.001780

6. Discussion of results of Fe-Cr-C with high Mn characteristics

The Fe-Cr-Mn alloy from this study overall has an austenitic structure (Fig. 1) similar to SS 316 L. As shown in the ternary diagram in Fig. 7, the perfect austenite structure is formed at Cr levels of about 14–18 % by weight and Mn 9–10 % by weight [17]. In cast objects, the shape and grain size of austenite are greatly influenced by the type of mold used. In sand molds, factors such as size, molding sand grain distribution, and mold permeability greatly affect the shape and grain size of the resulting alloy [16].

The Fe-Cr-C alloy under investigation has a hardness ranging from 231.8 to 298.4 VHN (Fig. 3). These numbers show that the hardness value of the Fe-Cr-C alloy is higher than that of SS 316 L (230.7 VHN). The increase in hardness along with the increase in tensile strength of the Fe-Cr-Mn alloy, where the tensile strength becomes higher with the increasing hardness value. The higher the Mn content, the greater the increase in hardness and tensile strength of the alloy. The tensile strength value of the alloy ranges from 522.69 to 680.89 MPa (Fig. 4). The high hardness value leads to increased wear resistance of the alloy, as indicated by the decreasing corrosion rate with the increasing Mn content, reaching the lowest rate at 20 wt. % Mn content, which is 0.000156 mm^2/kg.m (Fig. 6). This value is expected to be compatible with the hardness of human bone, so it can withstand wear due to friction with joint bones during use, similar to what happens with SS 316 L [20].

In addition to wear resistance, alloy toughness is required for bone implants. Unfortunately, increasing Mn content decreases the toughness of Fe-Cr-Mn alloys (Fig. 5). This is inversely proportional to the increase in hardness and tensile strength. However, the alloy toughness value at a Mn content of 0.16 J/mm^2 actually has a positive impact on bone implant applications, considering that SS 316 L is said to have a higher elastic modulus than human bones [19]. The minimum corrosion rate of Fe-Cr-Mn alloy in 0.9 % NaCl is 0.001780 mm/year on Fe-Cr-Mn alloy with Mn content of 20 wt. % (Fig. 7), still below the corrosion rate value of SS 316 L.

The Fe-Cr-C alloy's mechanical characteristics and corrosion rate statistics support the study's conclusion that it can be used as an alternative to SS 316 L. This material is suitable for applications where high tensile strength takes precedence over the ability to absorb impact energy, for example in components that experience high static loads but little impact or plastic deformation [11]. The selection of Mn content in the alloy should consider the needs of the application, especially if the material is faced with conditions that require resistance to friction or scraping. This material is also suitable for applications in designs that require high corrosion resistance. However, if the Fe-Cr-C alloy is to be employed as a biomaterial that is implanted in the human body, more improvement in the corrosion rate is required.

It should be noted that the Fe-Cr-C alloy used in this study is in the form of a cast product that has been homogenized through annealing. It would certainly be different if the alloy were produced using other methods, such as forging or rolling. Corrosion testing still uses 0.9 % NaCl and has not yet utilized body fluid formulas, so future research needs to adjust the corrosion testing media to be more relevant to human body fluid formulas.

7. Conclusions

1. The Fe-Cr-C alloy with 12, 16, and 20 weight % Mn added has an austenitic structure, meaning that the finer the austenite grains, the higher the Mn concentration.

2. The mechanical properties of Fe-Cr-Mn alloys with Mn content of 12, 16 and 20 wt. % are generally better than SS 316L. The hardness increased from 231.8 to 298.4 VHN, tensile increased from 522.69 to 680.89 MPa, elongation decreased from 55 to 38 %, impact increased from 0.213 to 0.169 J/mm^2, and wear rate also declined from 0.000184 to 0.000156 mm^3/kg.m.

3. The Fe-Cr-C alloy with a 20 % Mn concentration has corrosion resistance that is closest to that of SS 316L which is 0.00178 mm/yr.

If the Fe-Cr-C alloy is to be employed as a biomaterial that is implanted in the human body, more improvement in the corrosion rate is required.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Data will be made available on reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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