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Contribution to the Study of the Chemical and Microstructural Quality of Reinforcing Bars in DR. Congo "Case of the City of Lubumbashi"

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ABSTRACT: This research highlights the contribution to the study of the microstructural quality of reinforcing bars on the Lubumbashi market including bars imported from South Africa (FA), Zambia (FZ) and those produced locally (FC) by the only steel industry, in the former province of Katanga, the iron processing company SOTRAFER, in acronym.

The samples of the locally produced reinforcement bars (FC) were collected at SOTRAFER at the end of production, while the samples of the FA and FZ reinforcement bars were taken randomly on the Lushois market in a hardware store specializing in sales to avoid errors.

Microstructural analysis of all bars revealed a similar microstructure consisting of a ferrite (light areas) and pearlite (dark areas) matrix and a ferrito-pearlitic structure. This microstructure, as predicted by the Fe-C equilibrium diagram, could be justified by the carbon content (lower than the eutectoid point content); the results prove that all bars are hypoeutectoid steels ($\%C \leq 0.77$).

They can also be assimilated to the category of mild steels ($0.1 \leq \%C \leq 0.25$). This also shows that all the bars have not undergone a particular heat treatment and have been cooled very slowly in order to allow the diffusion of atoms and reach equilibrium conditions. The results obtained from the variance analyses of different materials of dimensions of 10, 12 and 16 mm revealed that at the level of chemical and mechanical analyses, there was no significant difference on all the parameters studied and that all the reinforcement bars could perfectly be used in construction. Finally, the survey reveals that FA is reputed to be of better quality among consumers, for several reasons including the psychological one although its price is lower than that produced locally.

KEYWORDS: Equivalent carbon, Hypoeutectoids, Microstructure, Reinforcement bars.

I. INTRODUCTION

Steel is known worldwide as the driving force behind the development of modern societies. This is the case in Europe. It is mainly used in the field of construction such as the manufacture of beams as well as for the production of utensils. [1] In fact, it is simply essential because its production is summarized in the steel industry treating oxidized iron ore, often rich by reductive fusion to obtain an iron-carbon alloy called steel or cast iron depending on the grade of carbon content. [2]

Given its many uses, specific additives, often metals, are added to obtain so-called alloy steels with particularly sought-after specific properties. [3] At the end of their life, steels are a special category of waste in the sense that they can be 100% recycled while retaining the same properties as the initial materials. [4]

Recycling is often done in an induction furnace and currently in view of environmental problems, the iron market is crowded with so-called "recycled" steels, especially since recycling has the advantage of saving so much raw materials. [5] While our country, the Democratic Republic of Congo, does not appear on any list of countries classified as steel producers, Australia and the Republic of South Africa come first respectively at the world and African level. This observation is a paradox because our country is full of iron ore resources, particularly in Haut-Katanga and in the western part of Congo, along the border with Cameroon and Gabon. [6]

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We need it all the more since we are in the reconstruction phase of our country. The consequence is that we are called upon to import steels. On the Lubumbashi market, our study area, there are mainly steels imported from Zambia (FZ) and those from South Africa (FA).

However, let us point out that our country has a history in iron production with the megaproject initiated at the time by President MOBUTU of the Maluku steel industry in Kinshasa which should be supplied by the scrap metal of vehicles but it unfortunately fell into disuse after a few years of operation. Currently, efforts are being made to produce construction materials locally. This is particularly the case for cement with the relaunch of CARILU in 2020 in Kolwezi and GCKA in 2022 in Likasi. In the field of steel industry, it should be noted that there is currently only one steel company in the province of Haut-Katanga, the iron processing company, SOTRAFER in acronym. This company with Indian capital has partly produced iron (FC) since 2007, after three years of construction of the plant and the start of the project, from the recycling of iron scrap in the form of waste in our environment. Its production is mainly reinforcing bars (reinforcement bars) used in construction.

Concerned about investigating in this area, this work was initiated with the aim of assessing the quality of the bars present on the Lubumbashi market in order to establish a clear diagnosis aimed at promoting this sector. Our procedure consists firstly in collecting by sampling the three types FA, FC and FZ. For ease, the FC samples are to be taken from SOTRAFER facilities after production while the FA and FZ samples are to be taken randomly from the market in a hardware store specializing in the sale of steels to avoid errors. As on the markets, we find the bars of 10, 12 and 16mm in diameter, these are the bars that are studied to assess their quality and establish a comparison. These samples are characterized on the chemical, mechanical and metallographic levels accompanied by a statistical analysis of the results. The whole is crowned by a survey of consumers to collect their sensitivity according to them.

II. MATERIALS AND METHODS

A survey was conducted in the city of Lubumbashi before proceeding with the various tests on the materials studied. It was carried out on men, women and legal entities. The numbers of men were 17, women 2, legal entities 3, sellers 18, buyers 22, users 18, people aged 18 to 25 15 and people aged 26 to 45 15 and one person aged 65. This makes a total of 100 people surveyed on the various samples of bars on the Lubumbashi market.

The analyses of the different samples were carried out within the company SOTRAFER. The production plant is located at latitude of 8711500 South, a longitude of 554750 East and latitude of 1245 m. Its head office is located at n°34, avenue soapmaker at the intersection with avenue Victim de la Rebellion, in the commune of Kampemba, city of Lubumbashi, Haut-Katanga Province, in the Democratic Republic of Congo.

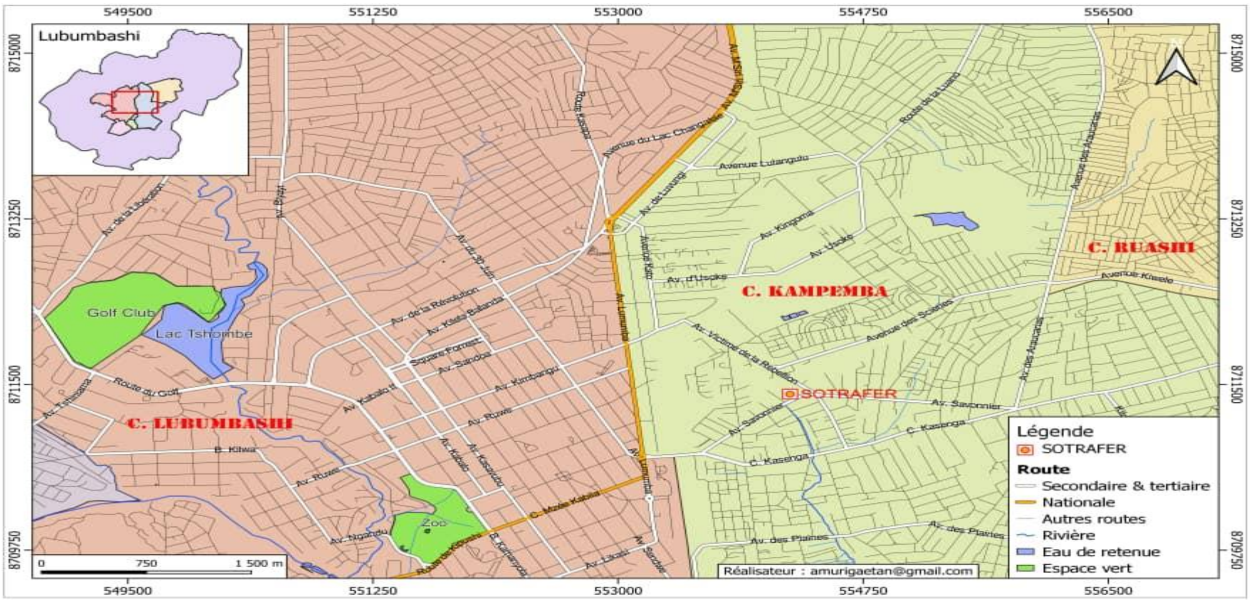

Fig.1. Mapping of the location of the company SOTRAFER/Lubumbashi (AMURI GAETAN)

The sampling of bars from South Africa, Zambia and those produced in the DRC, more precisely from the SOTRAFER company in Lubumbashi, was carried out randomly, once, over three years (2020, 2021 and 2022) in order to avoid estimation errors.

The procedure consisted firstly in collecting by sampling the three types FA, FC and FZ of the dimensions of 10, 12 and 16 mm in diameter, used a lot in construction. For reasons of convenience, the FC samples were taken in the SOTRAFER installations after production while the FA and FZ samples were taken randomly on the Lubumbashi market in a hardware store specializing in the sale of steels. These bars of different origin were studied to assess the quality in order to establish a clear diagnosis aimed at promoting this sector. These samples were characterized on the chemical, mechanical and microstructural levels, accompanied by a statistical analysis of the results. All this is crowned by a survey of consumers to collect their sensitivity according to them.

The bars from Zambia (FZ) and South Africa (FA) were purchased from the Lushois market, selecting three pieces of 6m length from 268 pieces of 10mm diameter bars constituting one tone, three pieces of 6m length from 188 pieces of 12mm diameter constituting one tone and three pieces of 6m length from 128 pieces of 16mm diameter constituting one tone.

For those of SOTRAFER (FC), the selection was made on the day of production of the 10 mm, 12 mm and 16 mm diameter bars. This selection was made because of 3 pieces of 6m length of the bars in a batch of 300 pieces diameter for all three dimensions. These different bars were designated by FA from South Africa, FZ from Zambia and FC from the Democratic Republic of Congo.

Fig.2. Samples of reinforcement bars of 10, 12 and 16 mm diameter

The reinforcement bars taken from the SOTRAFER facilities after production, as well as the various reinforcement bars purchased on the Lubumbashi market, were sent to the chemical and mechanical analysis laboratory of the Society de Transformation de Fir (SOTRAFER), followed by a microstructural analysis carried out at the metallographic analysis laboratory of the Polytechnic Faculty of the University of Lubumbashi, where a cutting was carried out according to the operating procedure of each analysis.

Chemical characterization was performed using the atomic emission spectrometer.[7,8] This device was accompanied by the sample preparation machine; the sample smoothing machine called sample machine.[9,10] Mechanical characterization was performed using the universal machine testing [11,12] and the bending test by the machine called bending test.[9,10] Microstructural characterization was carried out in three stages, including the one consisting of sample preparation (including cutting, coating, polishing); analysis of inclusion cleanliness and microcracks.

III. RESULTS

III. 1. Results of chemical characterization

The results of chemical characterization of 10, 12 and 16 mm diameter bars of FA, FZ and FC are given in Table 1

Table I. Results of the average compositions of the chemical characterization of FA, FC and FZ reinforcement bars of 10, 12 and 16 mm diameter

Nature	C (%)	Si (%)	Mn (%)	P (%)	S (%)	Cr (%)	Mo (%)	Ni (%)	Cu (%)	Al (%)	Nb (%)	Ti (%)	Co (%)	V (%)	Fe (%)	CE (%)
FA10	0,208	0,218	0,607	0,023	0,03	0,162	0,102	0,092	0,464	<0,010	<0,2	<0,22	0,015	<0,012	98,315	0,369
FC10	0,203	0,205	0,608	0,024	0,032	0,181	0,12	0,099	0,093	<0,011	<0,2	<0,21	0,015	<0,011	98,687	0,393
FZ10	0,192	0,181	0,586	0,022	0,017	0,164	0,043	0,087	0,175	<0,011	<0,2	<0,21	0,014	<0,012	98,375	0,363
FA12	0,199	0,165	0,561	0,024	0,027	0,187	0,076	0,114	0,117	<0,010	<0,2	<0,22	0,014	<0,011	98,37	0,38
FC12	0,198	0,251	0,6	0,035	0,028	0,173	0,098	0,105	0,106	<0,011	<0,2	<0,22	0,016	<0,012	98,29	0,393
FZ12	0,214	0,254	0,537	0,038	0,028	0,176	0,101	0,145	0,172	<0,011	<0,2	<0,22	0,016	<0,011	98,19	0,38
FA16	0,215	0,165	0,605	0,022	0,034	0,218	0,106	0,127	0,244	<0,011	<0,22	<0,22	0,017	<0,012	98,218	0,373
FC16	0,205	0,216	0,61	0,018	0,014	0,178	0,06	0,095	0	**<0,011**	**<0,021**	**<0,022**	0,025	<0,011	98,536	0,364
FZ16	0,217	0,164	0,585	0,015	0,019	0,203	0,089	0,141	0,254	<0,010	<0,2	<0,21	0,016	<0,011	98,156	0,358
Standard	0.15 - 0.25	0.15 - 0.25	0.50 - 0.75	0.055	0.055	0.35	0,008	0.008	0.3	0.35	<0.3	<0.06	<0.05	0.4	≥98	0.42

From the results of Table I it is clear that the chemical analysis of the samples showed that the studied bars are mainly composed of Fe (98.156-98.687%), Mn (0.537-0.608%), Cu (0-0.464%), Si (0.164-0.254%), C (0.192-0.204%), Cr (0.162-0.187%), Ni (0.087-0.145%), Mo (0.043-0.12%), P (0.015-0.038%), S (0.014-0.034%), Co (0.014-0.0254%) and the other chemical elements like Nb, Ti, V and Al are in trace form.

Examination of the results obtained in Table I shows that 12 chemical elements are within the margin of the international standard ISO 9001. Indeed, of all these elements, we find that iron is the most abundant element with a percentage above 98%. For steels, the most important main elements are iron and carbon which lead to the characterization of several grades. [13] In our case, the iron content is over 98%, while the carbon content varies from 0.19 to 0.22, confirming that we are in the presence of low-alloy steels, i.e. the iron and carbon content are within the range of the standard used. Other chemical elements such as Mn, Si, S, P, Mo and Cr are accompanying elements that give the steels the desired properties and accurately determine a good low-alloy steel in relation to the standard used ISO 9001. [14, 15]

Comparing the results obtained with the standard, we see that the carbon content impacts on weldability, hardness, corrosion resistance, tensile strength, resistance to weld decomposition, and the elastic limit on steels. [16]

The presence of Manganese in our samples contributes to mechanical resistance and forms sulfides by improving machinability while moderately increasing hardenability in cast iron and for steels this element prevents graphitization by strengthening the atomic bonds between Iron and Carbon, and playing the role of antidote to Sulfur because Sulfur is less harmful in the form of manganese sulfide, but harmful in the form of Iron sulfide or free Sulfur. [17]

Speaking of Silicon, the content is in the range of 0.16 to 0.25, which is within the standard. This element does not completely influence the properties of the steel but makes it more homogeneous when casting thanks to its reducing power to the formation of sulfides. Its importance when found in large quantities allows good deoxidation of the steel and improves the electrical resistivity, the resistance to oxidation of certain refractory steels and the required crystalline orientation of magnetic steel. Phosphorus has a content of 0.015 to 0.38, which is within the standard.

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The latter is a harmful element for steel when it exceeds the required standard and can cause a coarsening of the ferrite grain by increasing the brittleness of the steel and the breaking load while considerably reducing the plasticity and ductility. As for sulfur, its content varies from 0.014 to 0.034, which is also in accordance with the standard. This element is also harmful at high contents because it significantly influences the mechanical resistance of steels. [18] On the other hand, the high content of vanadium increases the wear resistance due to hard carbides as well as the heat resistance for hot working. [19]

II.13. Equivalent carbon

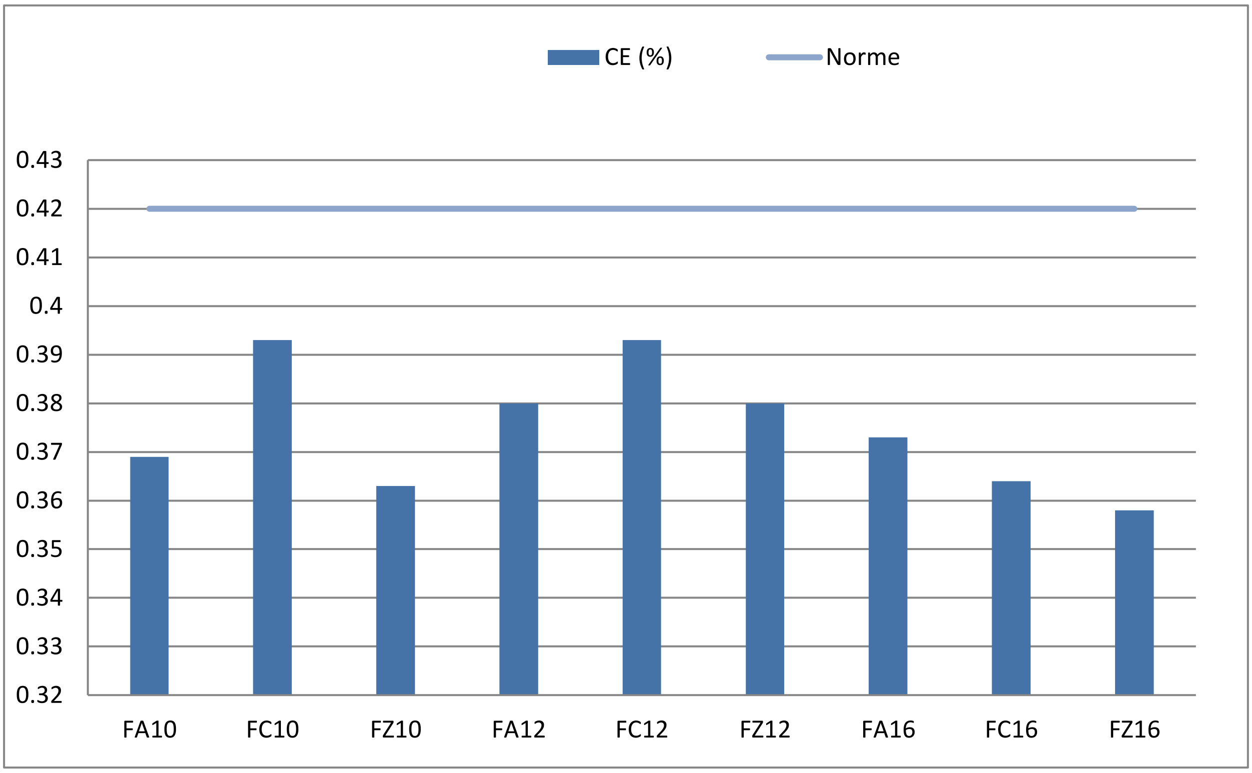

Fig.3. Equivalent carbon content

The histograms in Figure 3 show that the equivalent carbon calculated for each type of our samples meets the ISO 9001 standard. This calculation allowed us to justify the high contents of these three non-standard elements; hence they have no influence on our reinforcing bars. This type of steel is called steel with good weldability. [20, 21]

III.2. Metallographic Characterization Results

Analysis of the inclusion property and microcracks after obtaining a mirror polish for each sample under an optical microscope gave the images shown (Gr X1500) in the following figures:

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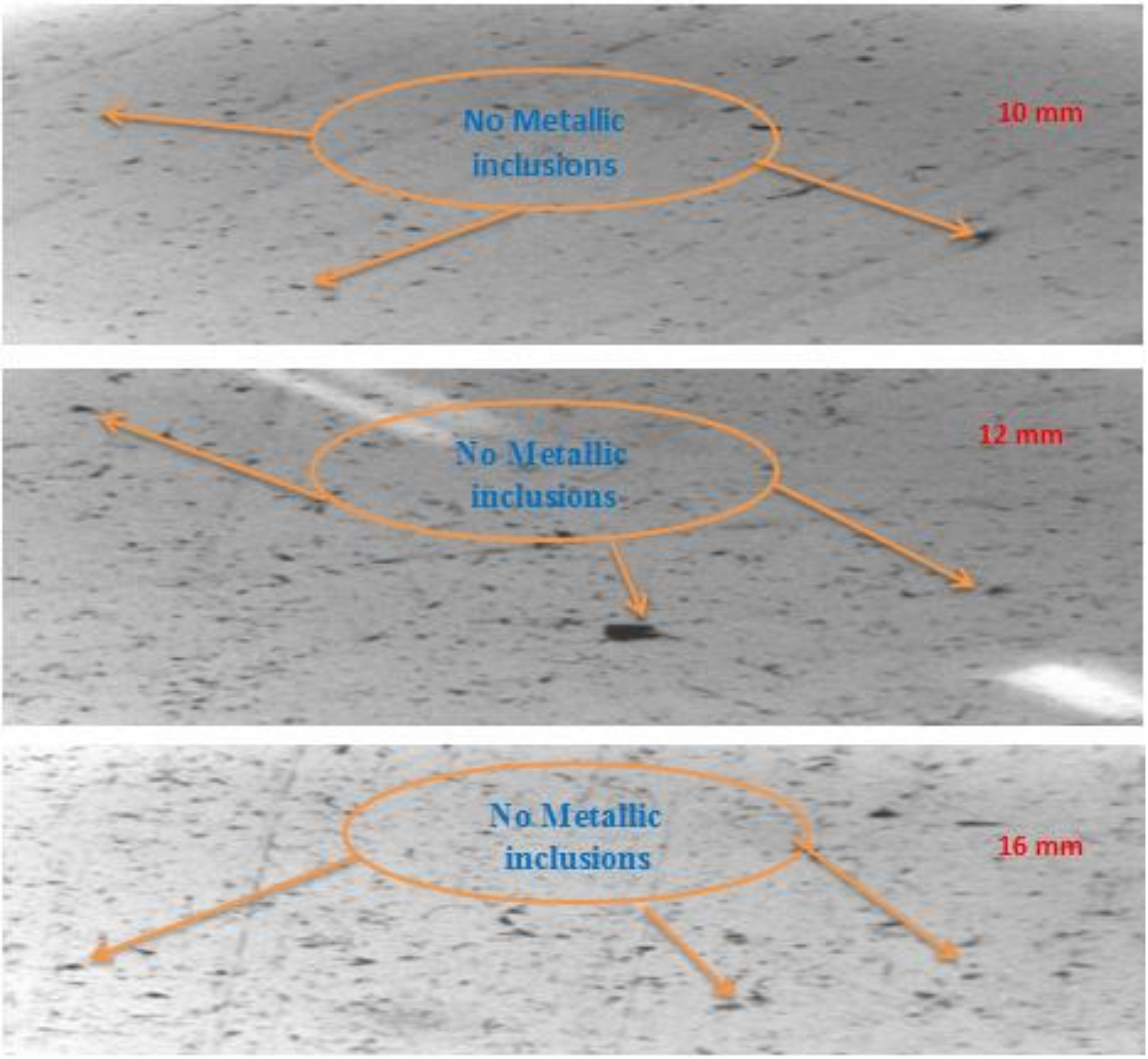
III.2.1. FC samples



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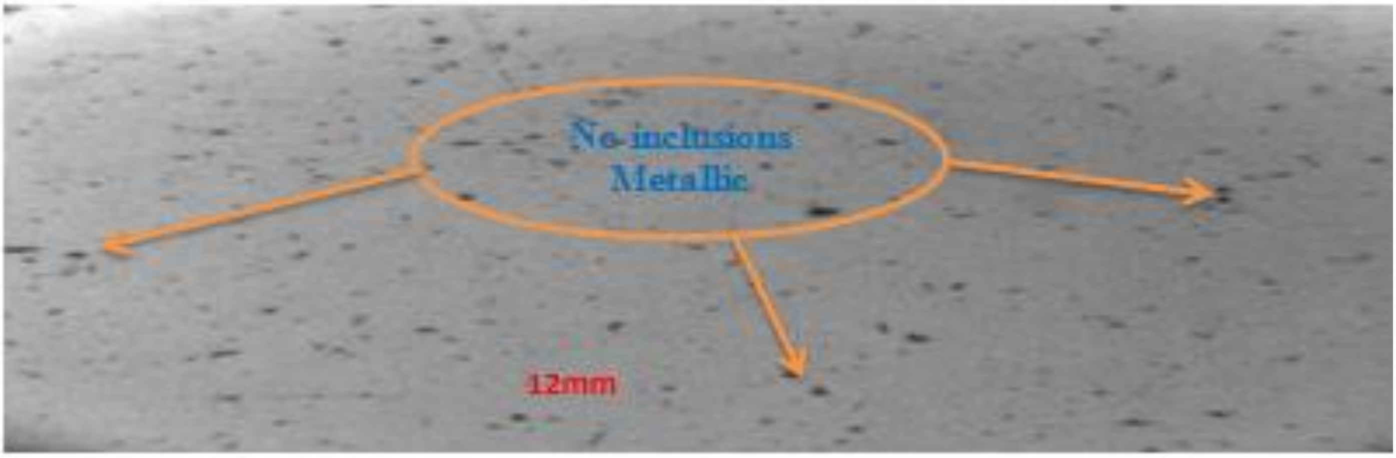
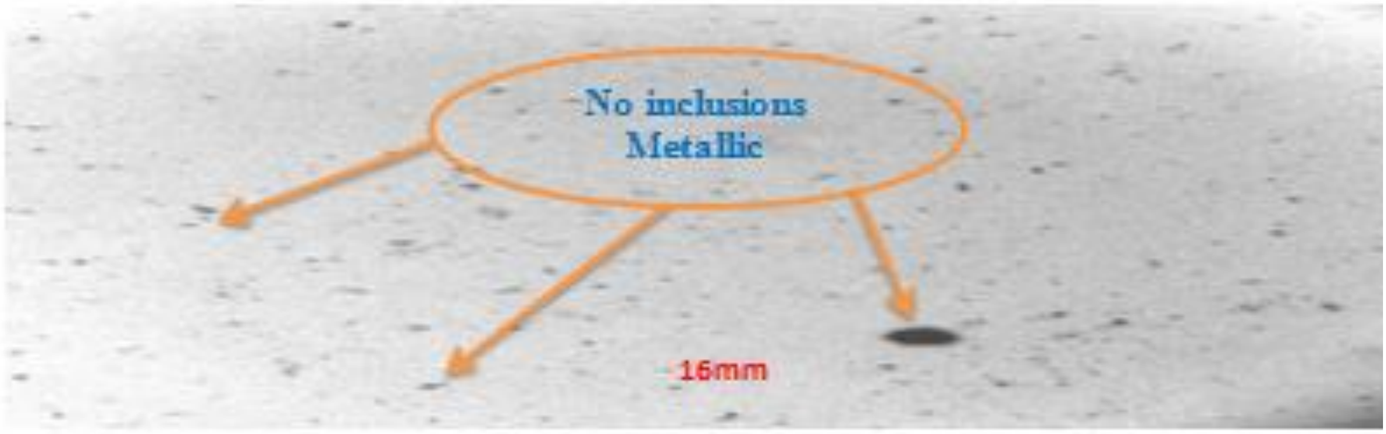
III.2.2. FA samples





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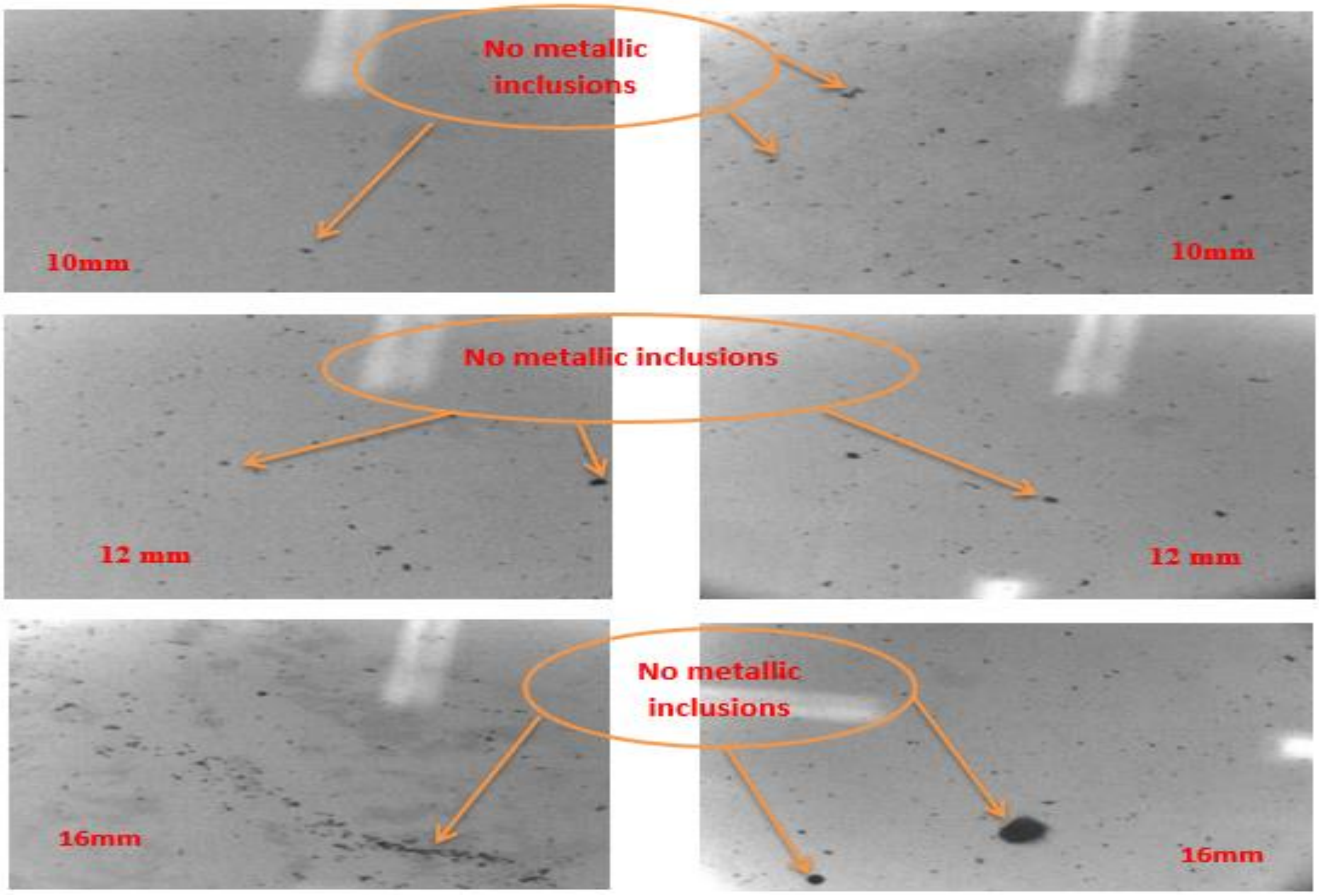
III.2.3. FZ samples



In view of the previous figures, it should be noted that all the reinforcing bars have defects of the type Non-metallic inclusions (black spots on the images). These defects can alter the hardness profile of the iron bars. However, all the samples do not have any microcracks.

The microstructural analysis of all the samples was observed after chemical attack of the Nital reagent, under an optical microscope and the microstructures are given in the following figures (Gr X1500):

III.2.4. FC samples

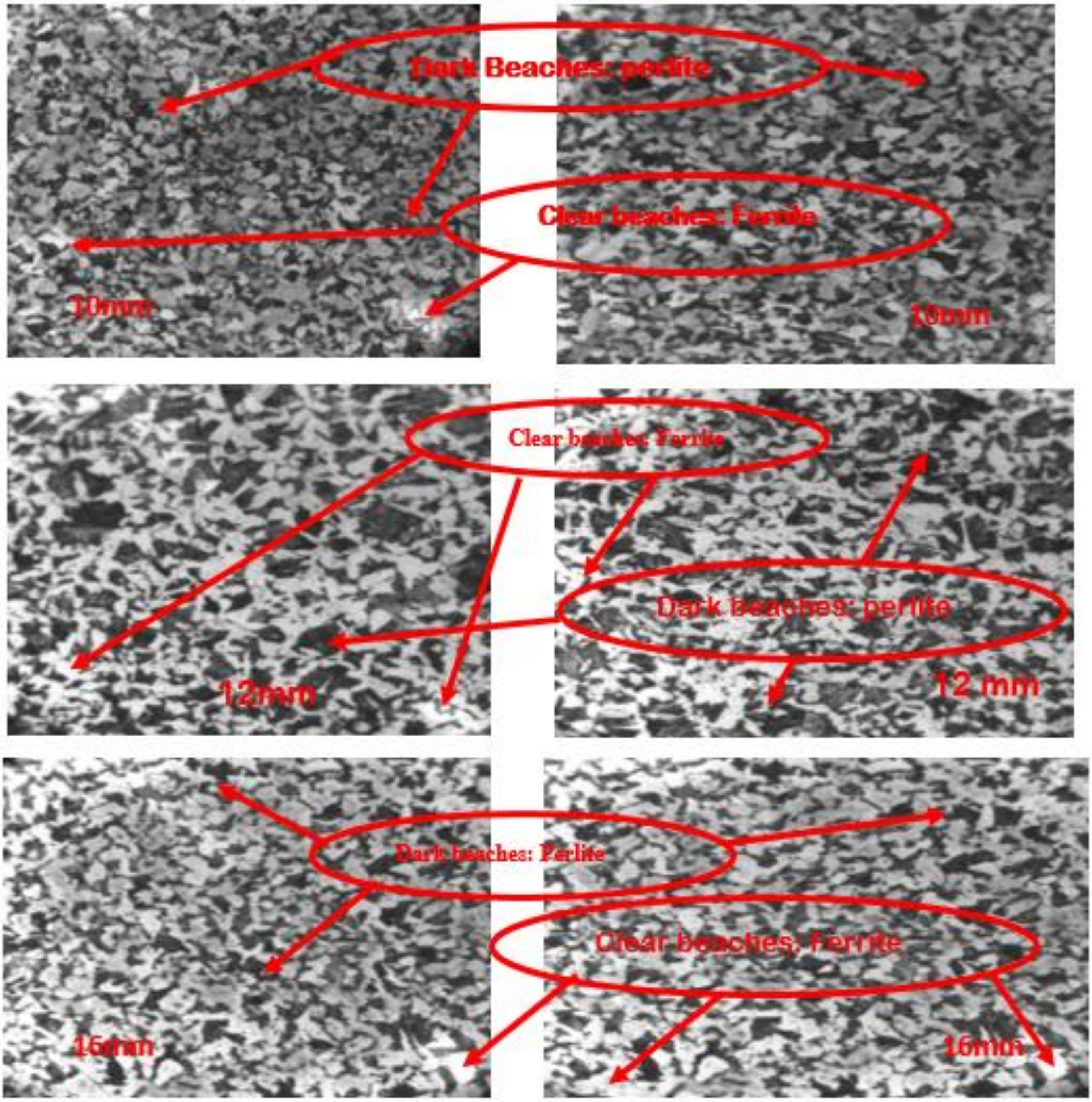


Fig.7. Inclusionary property and microcracks of FC

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III.2.5. FA samples

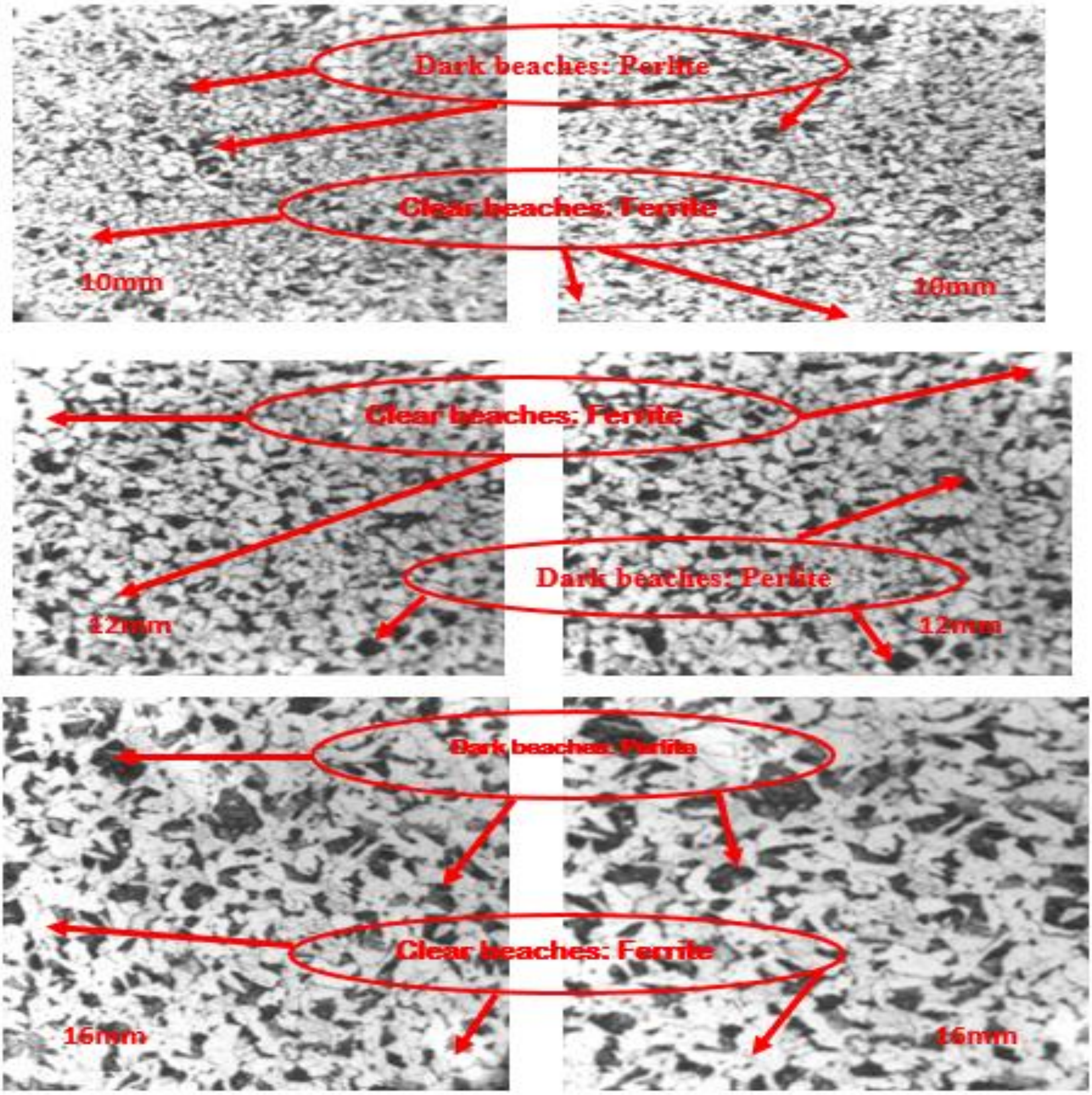

Fig.8. Inclusionary property and microcracks of FC

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III.2.6. FZ samples

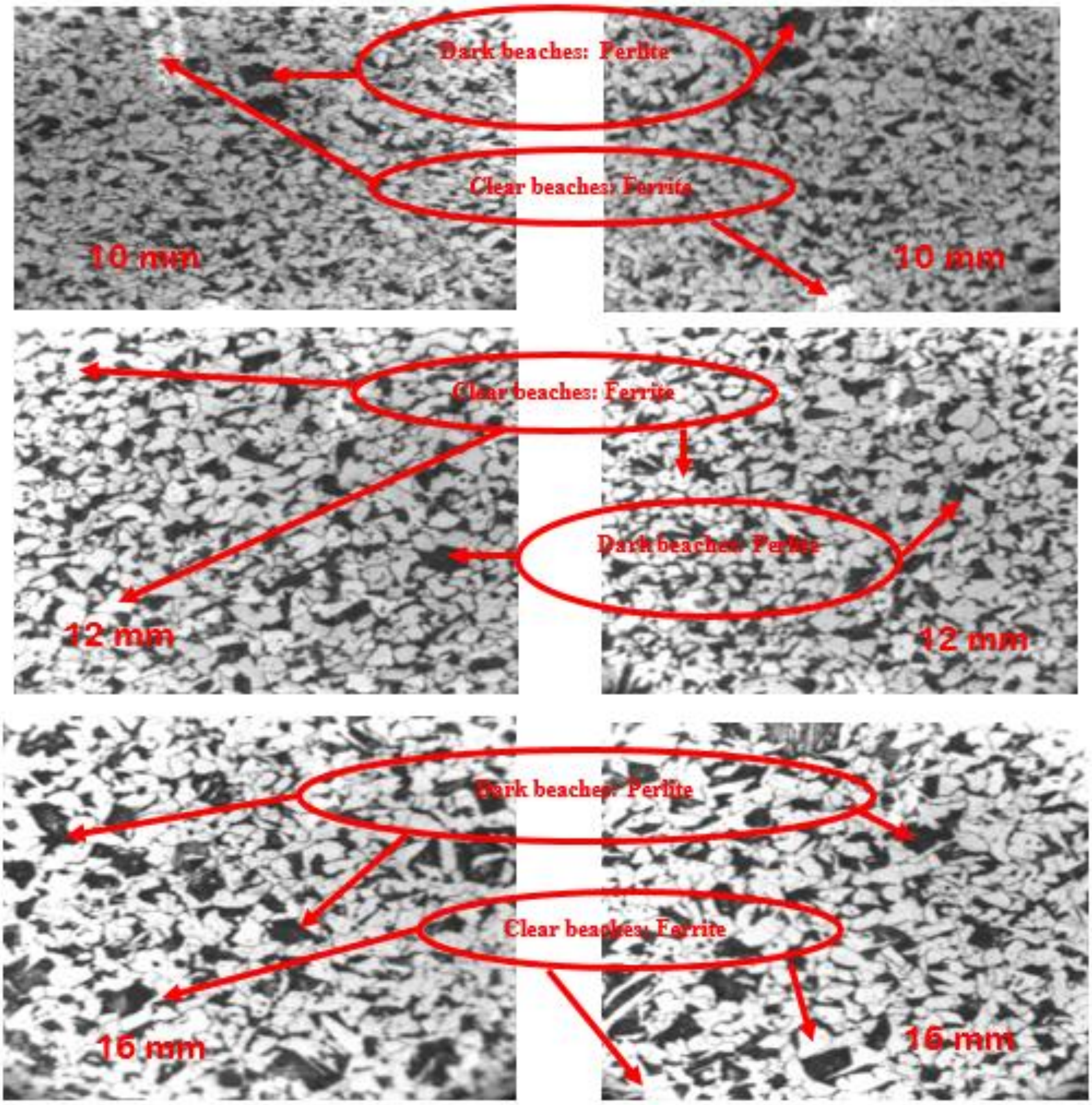

Fig. 9. Inclusionary property and microcracks of FZ

From the metallographic analysis images, it appears that all the bars have a similar microstructure consisting of a ferrite matrix (light areas) and pearlite (dark areas): ferrito-pearlitic structure. This microstructure, as predicted by the Fe-C equilibrium diagram, could be justified by the carbon content (lower than the eutectoid point content), it appears that all the bars are hypoeutectoid steels (%C $\leq$ 0.77). [22]

They can also be assimilated to the category of mild steels (0.1 $\leq$ %C $\leq$ 0.25). This also shows that all the bars have not undergone a particular heat treatment and have been cooled very slowly, so as to allow the diffusion of atoms and reach equilibrium conditions. These images corroborate the results of chemical analysis from the point of view of carbon content, confirming that we are in the presence of low-alloy steels [23]

CONCLUSION

This study aimed to evaluate the quality of bars produced locally in Lubumbashi and bars imported from South Africa (FA), Zambia (FZ) and those produced locally (FC) by the only steel industry in the province of Haut-Katanga, the Society de Transformation de Fir (SOTRAFER).

Indeed, the samples of locally produced reinforcement bars (FC) were collected at SOTRAFER at the end of production, while the samples of FA and FZ reinforcement bars were taken from the Lushois market in a hardware store specializing in sales.

Chemical characterization showed that the three natures of the reinforcing bars are similar with all the elements in the ISO 9001 standards which are Fe, Mn, Cu, Si, C, Cr, Ni, Mo, P, S, Nb, Co, Ti, V and Al, except three chemical elements: Mo, Ni and Cu. This gap is however attenuated by the equivalent carbon content.

Microstructural analysis of all bars revealed a similar microstructure consisting of ferrite (light areas) and pearlite (dark areas) matrix and ferrito-pearlitic structure. This microstructure, as predicted by the Fe-C equilibrium diagram, could be justified by the carbon content (lower than the eutectoid point content). The results prove that all bars are hypoeutectoid steels (%C ≤ 0.77). They can also be assimilated to the category of mild steels (0.1 ≤ %C ≤ 0.25). This also shows that not all the bars have undergone a particular heat treatment and have been cooled very slowly in order to allow the diffusion of atoms and reach equilibrium conditions.

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