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THERMAL INFLUENCE ON THE MICROSTRUCTURE AND THE MICRO HARDNESS OF A CARBON STEEL WELD PROBES

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Abstract:
During welding, the heat produced during the process can affect the microhardness and the microstructure of the material. The change in the microstructure and the microhardness can be discovered by carrying out a microhardness test on the welded sample and compare changes in the three different zones i.e the base, the weld and the Heat affected zone or by carrying out a micro structural examination on the welded sample and see the grain dispersion in relation to their sizes. In this work, weld quality of manual arc welded samples of low-carbon steel St3spdestined for bridge construction to be used in Cameroon has been investigated. After a chemical analysis of the material, a micro hardness test and a micro structural examination was also done. Results show that a composition of pearlite and ferrite was seen with the print of the id enter of the micro hardness test. The formation of pearlite and ferrite in base metalis composed of 20/80 respectively. For weld zone and HAZ it changes due to thermal processes. So the microstructure analysis shows that the base metal is a ferrite and pearlite having a grain size of 11-12 on a scale corresponding to an average grain diameter ≈ 7 microns. The structure of the weld metal is also made up of ferrite and pearlite with columnar crystals of cast metal. The HAZ is made up of Widmanstätten. The width of the HAZ zone is about 1,5 mm. In different areas of heat affected zone is observed fine-grained ferrite-pearlite structure with a high degree of dispersion.

Keywords: Defect; Reliability; Repair; Strength; Weld; Heat-Affected Zone; Tension; Low-Cycle Fatigue; Fracture; Microhardness; Microstructure; Elastic Modulus.

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1. Introduction

It is evident that no development can be gotten in a society without the concept of welding. The linkage of farm to market roads is an indication of development and when we talk of roads then we are talking of the construction of bridges which contains welded beam structures, or metal frames in houses and other structures are made up of welded joints. However, heat input and the cooling process after welding is done can largely influence the hardenabilty of that structure [1].

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A careful examination of a micro structure can show the change of the material hardenability in the different areas of the welded sample.

The heat of the arc causes both the core wire and the flux covering at the electrode tip to melt off as droplets. The molten metal collects in the weld pool and solidifies into the weld metal.Generally, the quality of a weld joint is directly affected by the input parameters during the welding process. Therefore, welding can be considered as a multi-input, multi-output process.

2. Materials and Methods

The welding process, chemical analysis and mechanical tests were conducted at the Institute of Physical and Technical Problems of the North namely V.P.Larionov of Siberian Department of Russian Academy of science in Yakutsk, capital city of Republic of Sakha (Yakutia), Russian Federation. The samples were welded and the metallurgical examination of these pieces were carried out in the technological institute of North Eastern Federal University namely M.K.Ammosov in Yakutsk. The following machines, consumables and metals were used for the purpose of conducting the experiments:

1) The probes cutting from 8mm thickness low-alloy steel (St3ps) sheet. The specific dimensions of probes are suitable for each test as specified by Russian GOST.
2) Standart filler material of mild steel ER70SG/2.4.
3) SMAW post with a diameter 3mm of electrode.
4) Universal Testing Machine (UTM)Z600 Zwick Roell.
5) Servohydraulic machineInstron 8802 for cycling test.
6) Rockwell scale B hardness tester.
7) Metallurgical microscopeNeophot-32.
8) Abrasive materials and grinding mashinefor polishing.
9) Spectroanalyser«Spectroport-F».

2.1. Preparation of Specimens

2.1.1. Preparation of Specimen for Welding

A flat plate steel material was cut to size and the edge preparation was carried out by creating a groove of 30^{o} on each end of the flat steel in order to get a 60^{o} groove angle with root face of 3mm. In order to achieve a very strong weld, the joints were properly cleaned with a grinder and sand paper and the required input parameter were respected such as the input current I= 110A, and the voltage at V=28 V.This sample was to be welded then cut into sizes according to the required test to be done.

2.1.2. Welding Process

To achieve the objectives of this study, the following basic steps were carefully carried out: selecting process parameters, doing an experimental design, executing the design, and measuring the output values. The chosen process parameters for this study were welding voltage, arc current, electrode size and gas flow rates. 30 run were carried out during the welding process, and a total of four different beads were achieved: 1. Root Run, 2. Hot Pass, 3. Fillingand 4. Capping. But

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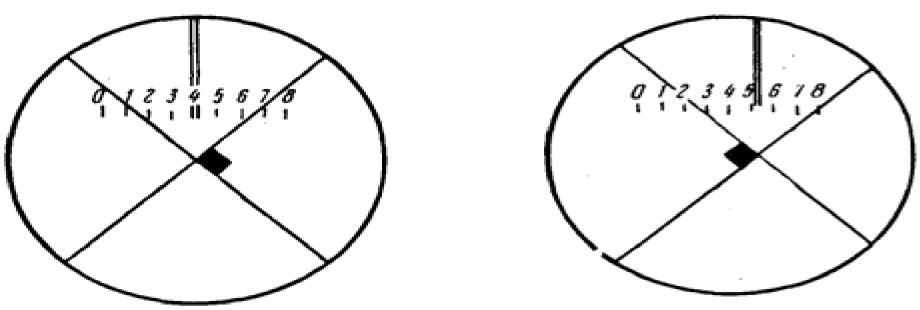
before these welding runs were made, the steel alloy of 8 mm thickness was cut into the required dimension with the help of lathe machine. The initial joint configuration was obtained by securing the plates in position using tack welding. Single V butt joint configuration was used to fabricate the joints using manual metal arc welding process. This welding was done on the both side of the material. All the necessary cares were taken to avoid the joint distortion and the joints were made with applying clamping fixtures. The specimens for testing were sectioned to the required sizes. The figures 1 and 2 show the final welded and polished samples cut to sizes.

Figure 1: Welded samples

. Figure 2: Polished Welded samples

2.1.3. Micro Hardness or Microstructural Investigation

The PMT-3 is a microscope used for the measuring of the micro hardness of the sample piece. This same device is used for both microhardness analysis and and microstructure analysis of metals pieces. The instrument consist of an indenter which has a rod and the displacement accuracy of 0.01 mm is achieved within 10 mm. Screw ocular micrometer consists of compensating eyepiece equipped with a reading device made of a screw, nut, measuring indicator drum and a carriage with a movable grid. Figure 3 represents the cone forming a pyramid used for evaluating the micro hardness [3].



Position 1 Position 2

Figure 3: Cones for micro hardness detection found inside the microscope

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Sampling for Microhardness Investigation

The piece for evaluation was cut on the base metal away from the welded zone, so as to determine the micro hardness of the HAZ, the welded zone and the base metal. The figure below shows three samples that were gotten from the low cyclic loading with with breakage points at different number of cycles.

The following steps are essential to follow when preparing the sample [4]. The piece for evaluation was cut on the base metal away from the welded zone, so as to determine the micro hardness of the HAZ, the welded zone and the base metal.

Figure 4: Sample pieces before preparation

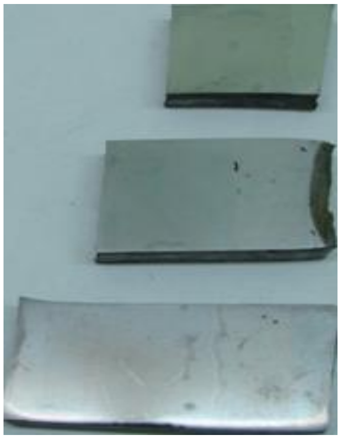

Figure 5: Sample pieces after preparation

The following steps were done so as to prepare the sample for evaluation

1) **Grinding of Samples**

Grinding should not warp nor distort the structure of the sample surface, sould not also destroy nor tear the fragile elements of the structure such as graphite and non-metallic inclusions in steel. Grinding is performed on samples grinder mounted with sand paper with progressively decreasing grain sizes consecutively as seen in the Figure 6.

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Figure 6: Sample grinder

During grinding, special attention should be paid to the fact that the pressure on the sample should be evenly distributed, and its entire surface is completely in contact with the paper. The plane of the section must be flat, without rounded edges. In conventional grinding abrasive layer with a depth of distorted structure can reach 75 microns. The most convenient abrasive grinding papers are produced by industry. The smaller the difference in grain sizes between the two series, the faster the grinding. At the end of grinding, thin section should be obtained without any scratches from the previous operation. Grinding papers of the following sizes and in ascending order are used: 120, 240, 360, 400, 600, 800 and 1000 [5].

2) Polishing of Samples

Polishing metallographic samples is carried out to remove the existing surface roughness after grinding. Polishing is done with the help of a flat disk covered with taut, dense and soft of high quality material and a diamond paste is applied on the surface of the metal piece. The figure below presenst materials used for polishing.

Figure 7: Materials for polishing

The duration of polishing vary from one metal to the other. However, its completion will depend on its examination on the microscope to be sure that metal surface can be as reflecive as much as possible.

3) Etching

The purpose of etching is to enable the easy detection of the micro structure of the material. Various reagents are used to identify the microstructure of steel, cast iron and non-ferrous metals.

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Many of them are weak alcoholic solutions, or simply aqueous weak solution reducing the etching speed. The smaller and more heterogeneous structure, the faster it is etched and the more the magnification will be seen in the microscope. After etching, thorough washed with a strong jet of water, dried with filter paper, and then inspecting the thin section through the microscope in order to determine whether the detected result is sufficient for the microstructure. If the structure found is not sufficient, a second grinding is etched. In preparing the sample for etching, the solution necessary to use should be chemically pure reagents, such as rectified alcohol and distilled water [4]. The figure below represents the finished samples ready for evaluation.

Figure 8: Finish sample

3. Processing of the Data

The number of micro-hardness H is defined as the ratio of the load to the print area:

$$H_{\mu} = \frac{2P\sin\frac{\alpha}{2}}{d^2} = 1{,}8544\frac{P}{d^2}$$

where α - angle at the apex between opposite faces of the quadrangular pyramid with a square base, equal to 136°; P - load in kilograms; d - diagonal length in mm.

The standard deviation is calculated using the formula:

$$\sigma = \sqrt{\frac{1}{m-1}\sum_{k=1}^{m}(n_{cp} - n_k)^2}$$

3.1. Methods

3.1.1. Chemical Analysis

In order to determine the chemical analysis of the material, a set of apparatus called a spectroanalyser was used: It is compose of a CPU, a monitor and a gas bottle filled with argon. Table 1shows the average values of chemical elements.Average value of chemical composition of the sample was calculated from three values of spectral analysis of each element on the «Spectroport-F» set-up

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Table 1: Result of chemical analysis of material

Fe	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Co	Cu	Nb	Ti	V	Zr	As
98.9	.183	.236	.397	.004	.32	.029	.011	.034	.046	.006	.04	.002	.002	.002	.002	.005

Comparing this result with the table data of chemical composition of the chosen materiali. eSt3ps [2] (see Table 2). Table 3 gives the known characteristics of St3ps.

Table 2: The chemical composition of the material in% St3ps [9]

C	Si	Mn	Ni	S	P	Cr	N	Cu	As
0.14-0.22	0.05-0.15	0.4-0.65	< 0.3	< 0.05	< 0.04	< 0.3	< 0.008	< 0.3	< 0.08

Table 3: Characteristics of St3ps

Steel Mark	St3ps
Classification:	Structural carbon steel of ordinary quality
Addition:	GOST 27772-88 steel St3ps matches steel for building structures S275
Application:	Bearing elements of welded and non-welded structures and components operating at positive temperatures, fittings At400S class

3.2. Microstructure

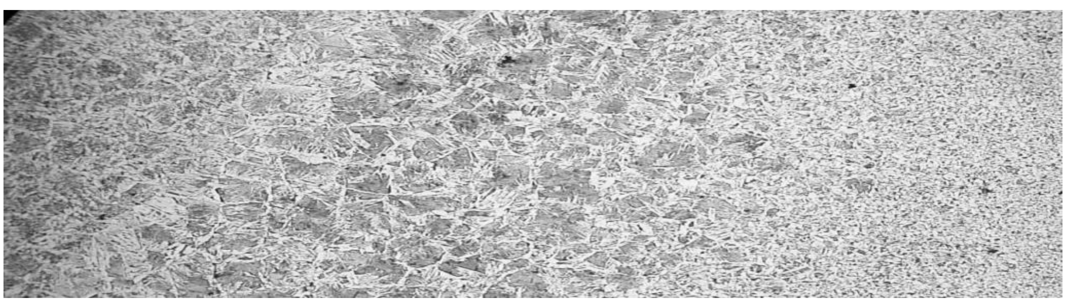
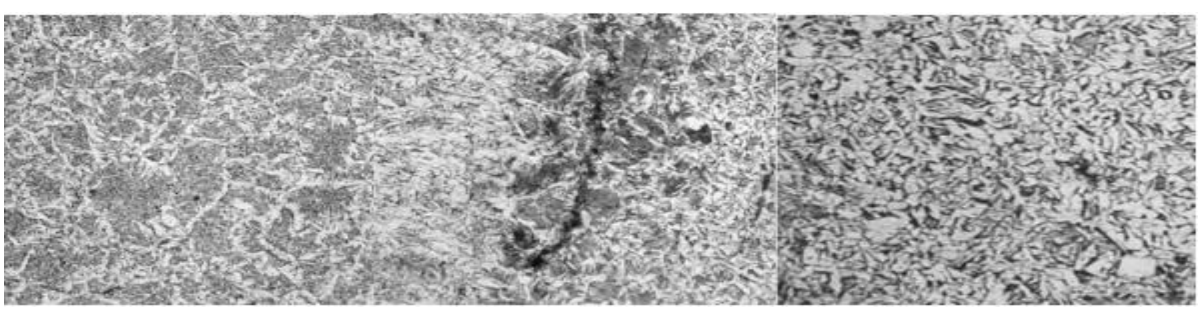


Figure 9: Microstructure of weld, HAZ and base metal in the probe, ×500

Analysis of the microstructure of the base metal, weld metal and heat affected zone of the sample number 7 was performed using metallographic microscope "Neophot-32".



a b c

Figure 10: Microstructure of the weld (a), HAZ (b) and base metal (c) in the probe, ×250.

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3.2.1. Microhardness Analysis

The following datum is results of the micro hardness test and was obtained from three samples after mechanical test [6]:
Sample 1: Initial point with the lowest number of cycles with breakage at the welded zone
Sample 3: Sample with highest number of cycles breaking around the welded zone
Sample 7: Sample with the highest number of cycles with breakage at base metal.
The results for three samples are presented below in table 4 and on Figure 11. The higher values accord to weld zone, the lowest correspond to HAZ and base metal is on the right part of curves.

Table 4: Sample zone analysis

Sample 1	Sample 3	Sample 7
Welded Zone from 1-7	Welded Zone from No. 1-11	Base metal from No. 1-6
HAZ sample 8-9	HAZ No. 12-13	HAZ Sample 7-8
Base metal from 10-30	Base metal No. 14- 35	Welded Zone No. 9-19
		HAZ Sample 20-21
		Base metal from No. 22-50

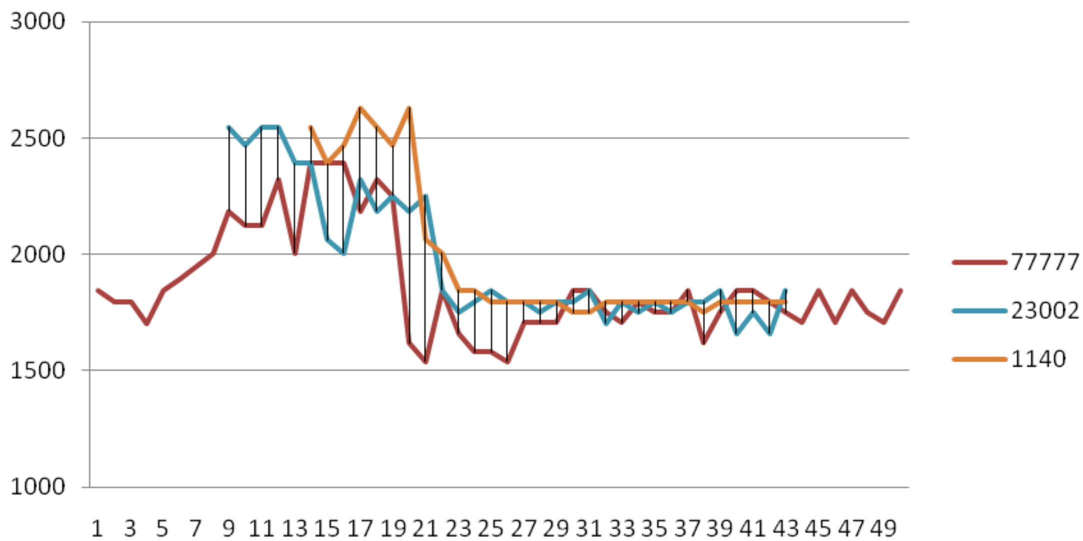

Figure 11: The micro hardness distribution in welded low-cycled samples: y-axis is microhardness value, MPa; x-axis is distance from the sampleedge, mm

4. Results and Discussion

Composition of perlite and ferrite was seen with the print of the identer of the microhardness test. The formation of perlite and ferrite in base metal is composed of 20/80 respectively. For weld zone and HAZ it changes due to themal processes.

So, the microstructure analysis shows that the base metal is a ferrite and pearlite having a grain size of 11-12 on a scale corresponding to an average grain diameter ≈ 7 microns (see Figure 6, c). The structure of the weld metal is also made up of ferrite and pearlite (see Figure 10, a) with columnar crystals of cast metal. The HAZ is made up of Widmanstätten figures [7] (see Figure 6,

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b). The width of the HAZ zone is about 1,5 mm. In different areas of heat affected zone is observed fine-grained ferrite-pearlite structure with a high degree of dispersion [8]. Figure 10, b shows a microcrack with the length 1,7 mm in the HAZ of sample number 7. In the weld zone of this same probe 1,2 mm length microcrack was revealed also.

The main result of this work is that, the heterogeneity caused by weld could be measured by the structural and microhardness tests for futher numerical analysis. Nevetheless the differences in failure for low-cycling fatigue test probes caused by weld defects could be modeled both by mechanics of continua and fracture mechanics.

5. Conclusion

The focus of the research is to estimate the inhomogeneity of specimen due to weld, so as to prepare the initial data for numerical modeling. This structural research reveals the differences in microhardness conditioned by phase distribution due to the thermal influence in the weld, heat affected zone and base metal. Knowing these differences in the divergence of the microhardness and microstructure will serve as indicators of failure thus will permit the timely intervention of maintenance of bridge structures so as to avoid catastrophic failure leading to heavy loss of lives and properties therby beneficial to road users, investors and the nation as a whole.

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