ANALYSIS OF THE MEASUREMENT OF INTERLAMELLAR SPACING OF PEARLITE IN EUTECTOID STEEL

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Abstract

Many alloys that have lamellar structures, e.g., pearlitic steel, are widely used in practice. For the evaluation of the quality of steel wires for tyre cords, springs and ropes are studied extensively at our laboratory of wire drawing. An important prerequisite for right evaluation is the accuracy and consistency of the evaluation of true interlamellar spacing from microstructural observations. In this paper we used the basic techniques for evaluating whether there are significant differences in the measurement of interlamellar spacing among different researchers. For this purpose were produced samples of steel wire by the straight-through single-block KOCH KGT 25 - E wire drawing machine. The analysis was performed on the 1.5 and 3.4 mm wires from C78D steel for ropes with various degrees of deformation.

Keywords: Interlamellar spacing, pearlite, wire, drawing

1. INTRODUCTION

The microstructure of pearlite is described using three parameters: interlamellar spacing (IS), the size of a pearlite colony and the volume fraction of cementite. The most important of these is the IS defined as the perpendicular distance across two consecutive lamellae, e.g., ferrite and cementite. During wire drawing, IS decreases with increasing amount of strain. The deformation of pearlite occurs in three stages. In the first stage, deformation takes place in ferrite lamellae. In the second stage, cementite lamellae bend and rotate. Finally, the cementite lamellae deform and break up [1, 2].

2. DESCRIPTION OF ANALYSIS

The wire was drawn from the diameter of 3.4 mm to 1.5 mm using straight-through single-block KOCH KGT 25 - E wire drawing machine with a drawing block diameter of 600 mm and a water-cooled rotating drawing die holder. Following each pass, a length of wire sufficient for metallographic analysis and mechanical testing was taken from the drawn stock [3]. Metallographic analysis was conducted on scanning electron micrographs (SEM) of the wire axis area. A total of 15 photographs were taken on each pass, using the magnification of 10000×. The micrographs were taken in a consecutive sequence of adjacent locations so that the selection of the area did not affect the subsequent analysis. For the purposes of analysis three trained researchers measured 15 microstructures of initial wire (3.4 mm) and 15 microstructures after the last pass (1.5mm). Each researcher found out the number of pearlite colonies, the length of individual colonies and the number of lamellas in these colonies. Based on these values the average IS values were calculated.

3. ANALYSIS RESULTS

For the values of IS were constructed histograms for all researchers and for all found colonies in all microstructures (see **Figure 1**).

From the analysis of constructed histograms for samples after the final pass is evident, that IS values found out by researchers A and B are approximately the same. The researcher C achieved similar values as the first two researchers, but in total we can see tendency to the bigger IS values measured by this researcher. For

verification of this assumption was in the Minitab 16 software performed Mann-Whitney test, which compares the probability distributions of two population [4, 5].

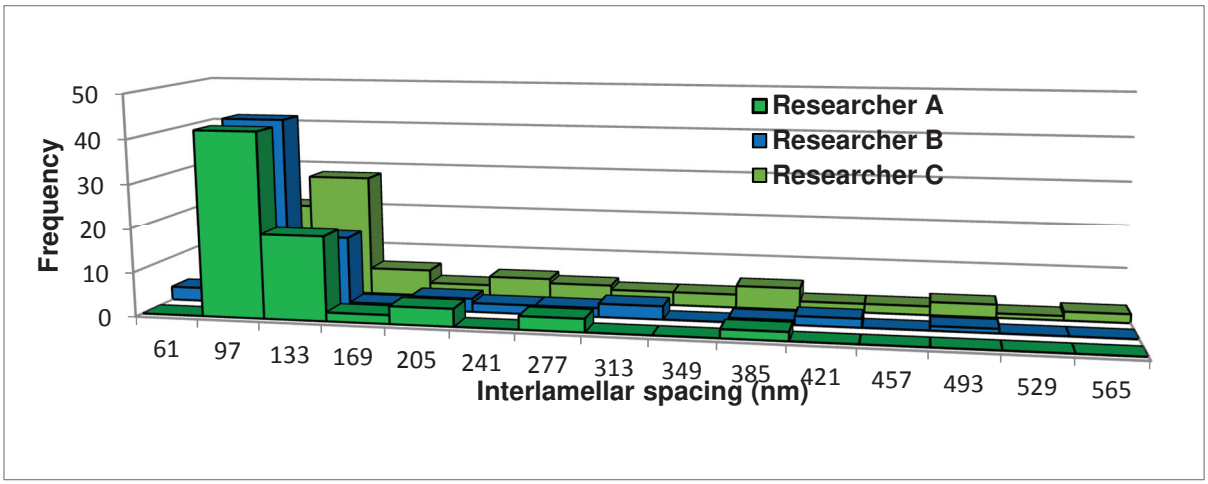

Figure 1 Histograms of measured IS for all researcher

The results of this test (see **Table 1),** showed that the probability distribution of IS values is in the case of researcher C different from two remaining researchers (confidence interval does not include 0).

Table 1 Results of Mann-Whitney test

Researchers	N	Point estimate for median difference	95 % Conf. Interval for difference between operators
A vs B	72;78	4.76	(-3.57;12.85)
A vs C	72;89	-30.66	(-46.67;-18.32)
B vs C	78;89	-35.00	(-50.01;-21.97)

The different evaluation of researchers can be caused by different number of found colonies (see **Figure 2**).

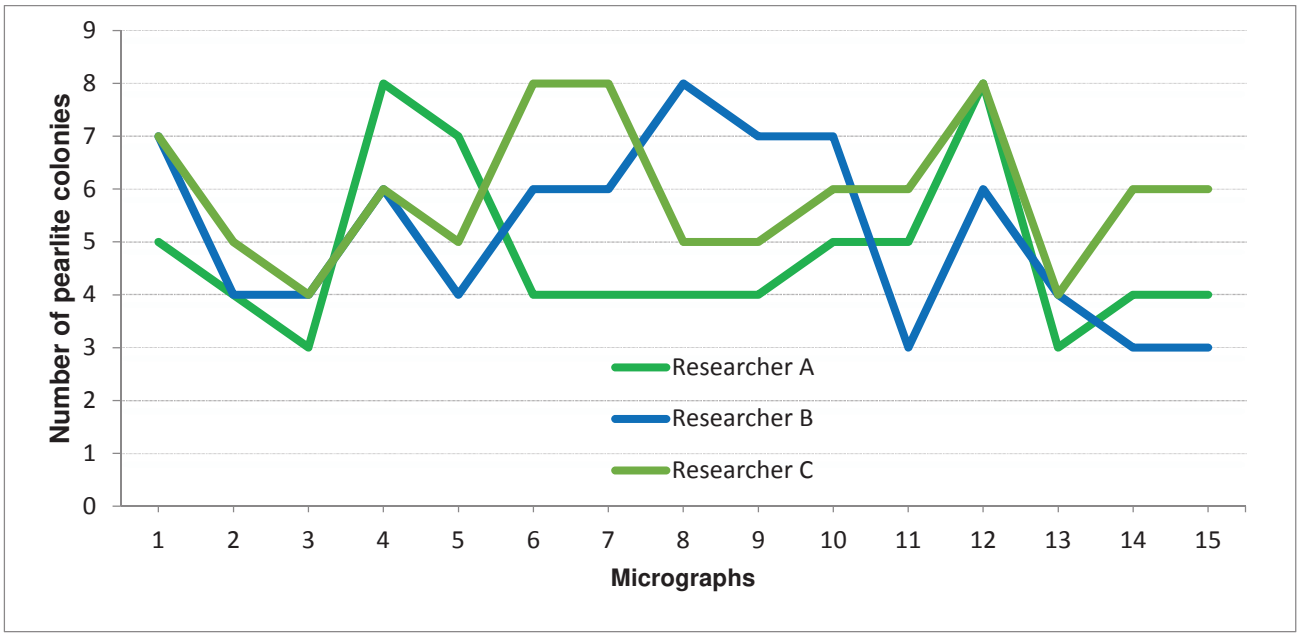

Figure 2 Number of pearlite colonies found by researchers

If is the number of pearlite colonies found by researchers strongly different for initial and final samples was found with the help of construction of contingence tables for the number of identifiable colonies and subsequent evaluation by the help chi-square independence test [6]. Below is displayed contingence table for researchers A and B (see **Table 2**).

Table 2 Contingency table for researchers A and B.

Researcher	Specimens (microstructure)		∑
	Initial (3.4 mm)	Final (1.5 mm)	
A	229	78	307
B	223	72	295
∑	452	150	602

From the results performed by chi-square independence tests is clear, that the number of found colonies is not dependent on thy degree of deformation of pearlite colonies. For all pairs of researchers was accepted null hypothesis, that means that the characteristic are independent. From these reasons an experienced specialist, concerning metallurgy and forming technology in details evaluated two microstructures (**Figure 3** and **Figure 4**), where the results of researchers evaluation were the most different. The results of this evaluation are clearly processed in **Table 3** and **Table 4**.

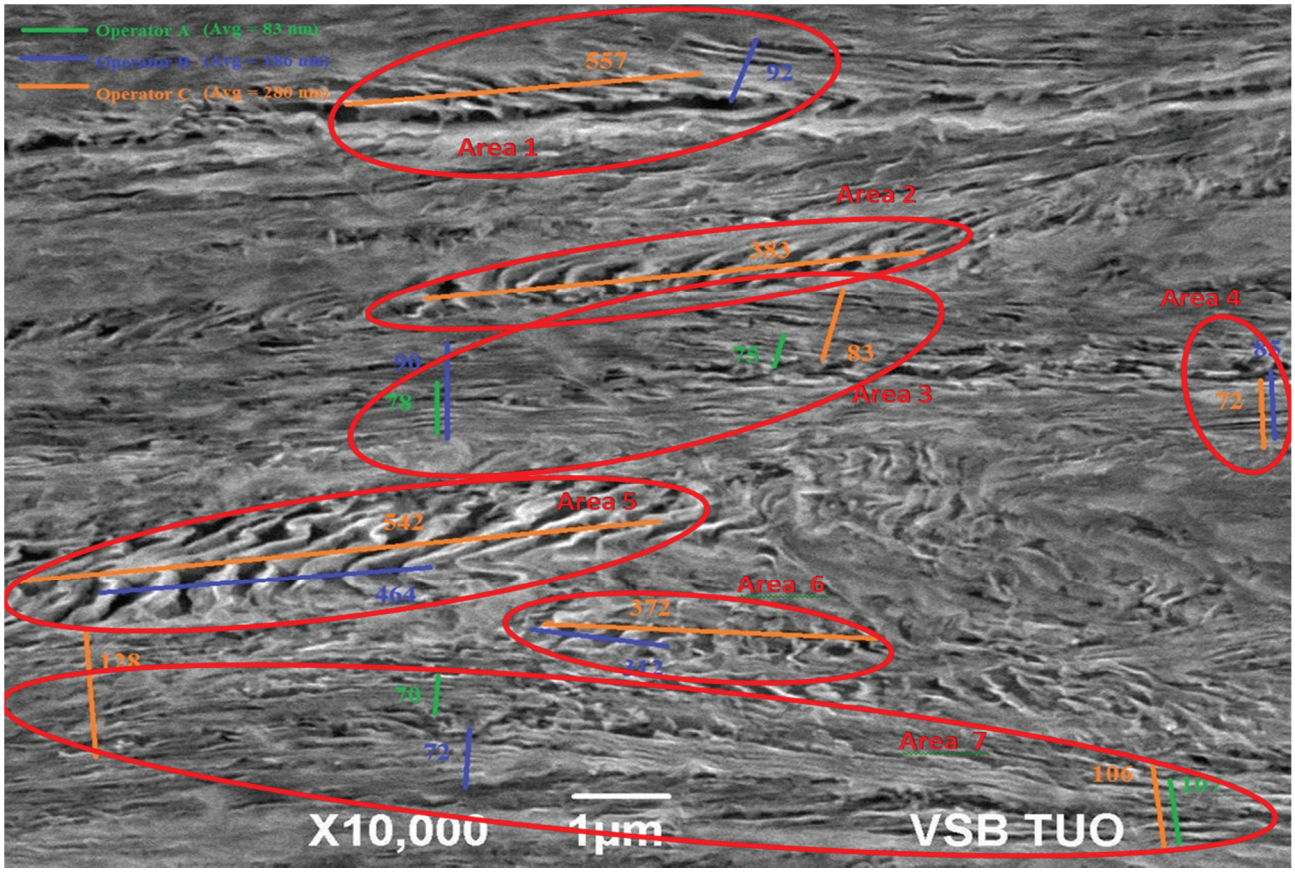

Figure 3 Micrographs of wire upon final pass (sample 6)

Table 3 Comments of sample 6

Area	Researcher			Comment
	A	B	C	
1	No result	**92**	557	The assessed colony has areas with considerably different IS as a result of unfavorable initial orientation of the lamellas. The researcher B chose area which is more characteristic for a given colony. Moreover the measuring line of researcher C is not perpendicular to the lamellas (deviation from the perpendicular is in this case more than 60 °).
2	No result	No result	**383**	Researchers A and B did not measure this colony, but it is different colony than in area 1. But the measuring line of researcher C is not ideal perpendicular.
3	78 and 75	**90**	**83**	The Relatively good agreement is among researchers. However the Researcher 1 measured this colony twice (from the average IS is evident that it is the same colony).
4	72	85	**No result**	It is possible that it is the same colony, which was measured in area 3.It is also confirmed by very similar values of IS.
5	No result	**464**	542	The Assessed colony has areas with very different IS as a result of unfavorable initial orientation of the lamellas. The Measuring line of researcher C crosses some lamellas under too acute angle. The researcher B which used shorter measuring line had in these case better results.
6	No result	312	**372**	The measuring line of researcher C is longer.
7	**70** and 107	**72**	128 and 106	It is the only colony that researchers A and C counted twice. In addition, these researchers chose the area totally on the right, where seems to be few lamellas , which are so close to each other that it is not possible to distinguish them. However, if we check their continuation it is clear that there are more lamellas.
* Bold character indicate the value, that has been assessed as the best value of IS.				

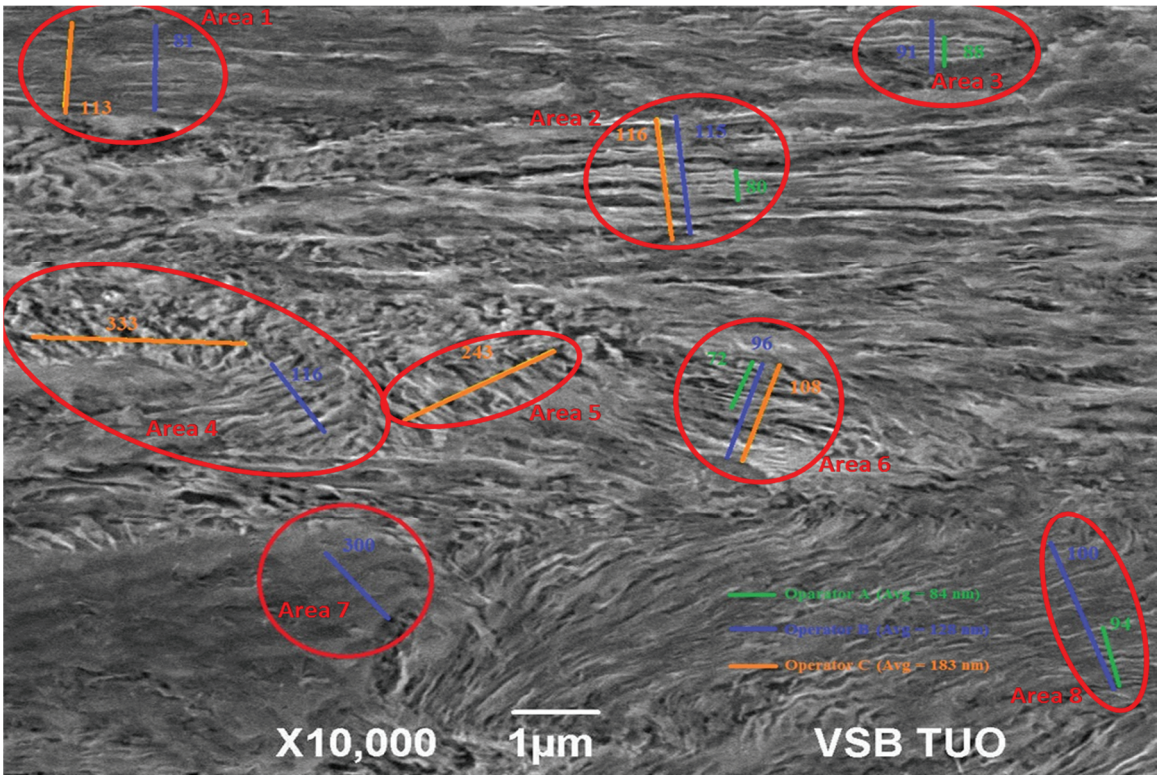

Figure 4 Micrographs of wire upon final pass (sample 9)

Table 4 Comments of sample 9

Area	Researcher			Comment
	A	B	C	
1	No result	**81**	113	The lamellas on the border of distinctiveness. Researcher C did not count some lamellas.
2	80	**115**	**116**	Researcher A used too short measuring line and did not count areas with bigger IS in the colony.
3	88	91	**No result**	It is the same colony like in area 1.
4	No result	**116**	333	Colony with complicated orientation of the lamellas. Researchers B and C measures each a little bit different area, however the measuring line of researcher C is not perpendicular to the lamellas.
5	No result	No result	**243**	This colony is difficult to identify. Researchers A and B considered this area as the continuation of the colony from the 4th area.
6	72	**96**	108	A rare consensus on the location of the measuring lines, but significant differences in the average IS values. Researcher A used too short the measuring line. Researcher 1 used too short the measuring line. Researcher C evaluated some lamellas located close to each other as a single lamellae.
7	No result	**300**	No result	Very rare area where the lamellas enclose with the observation plane very acute angle and thus form a sort of rungs, which are difficult to distinguish [7].
8	**94**	**100**	No result	Very big colony immediately adjacent the areas 6 and 7. Researchers A and B achieved very similar values of IS, even if the researcher A used short measuring line.
* Bold character indicate the value, that has been assessed as the best value of IS.				

By the analysis of the most different results of the evaluation of researchers was defined these problem areas of IS calculation:

- the measurement of one colony more times,
- the measuring lines are not perpendicular to the lamellas,
- too short measuring line not intersecting all the lamellas in given colony,
- acute angle of the lamellas to the observation plane.

4. CONCLUSION

Based on the analysis of measurement of IS presented in this paper was found several problematic areas respectively weaknesses in the researchers evaluation. Better evaluation of the IS can be achieved through a detailed study of the root causes of found weaknesses [8]. Pictures of the microstructures used for this analysis can be used for illustrative presentation of the most difficult identifiable colonies or lamellas and may be also useful for the presentation of the most common mistakes in the measurement of IS. For better evaluation of IS might also contribute improved preparation of specimens, in which prevent merging respectively deformation of the individual lamellas or colonies. Our further research will be focused predominantly at these issues.

ACKNOWLEDGEMENTS

This paper was elaborated in the frame of the specific research project SP2016/107, which has been solved at the Faculty of Metallurgy and Materials Engineering, VŠB-TU Ostrava with the support of Ministry of Education, Youth and Sports, Czech Republic.

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