EVOLUTION OF TRUE INTERLAMELLAR SPACING OF PEARLITE DURING STEEL WIRE DRAWING WITH DIFFERENT SINGLE PASS REDUCTION AND ITS EFFECT ON MECHANICAL PROPERTIES.

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Abstract

The experimental material was a drawn and patented 3.4 mm diameter wire from C78DP steel. The wire was drawn from the diameter of 3.4 mm to 1.5 mm using a straight-through single-block KOCH KGT 25 - E wire drawing machine. Two pass schedules were used with different one-pass reduction. Metallographic analysis was conducted on scanning electron micrographs (SEM) of the wire axis area. True interlamellar spacing (IS) was determined for all individual passes by statistical analysis of the measured apparent IS. Histograms constructed using true measured data were compared with each other passes for both pass schedules. Both a tensile test and a torsion test were conducted. The evolution of the measured mechanical properties (ultimate tensile strength, elongation to fracture and shear strain to fracture) was compared with the evolution of the true IS. We confirmed that there is a strong correlation between true IS and tensile strength or elongation to fracture. We also discovered that low cycle toughness represented by shear strain to fracture reached the maximum value before the deformation of cementite lamellae starts. From this viewpoint, we also mutually compared both pass schedules.

Keywords: Wire drawing, interlamellar spacing, mechanical properties, steel

1. INTRODUCTION

In the previous paper [1] we presented the methodology for determining the true interlamellar spacing of pearlite in the post-patenting state, but also after plastic deformation. This methodology, which is based on principles of mathematical statistics, is based on the previous papers from authors Ridley, Park, Pellisier and Ikeda [2 - 5]. In this paper we shall present the utilization of this methodology when comparing the drawing of wire for steel wire ropes according to two various drawing schedules with the same total deformation but differing in the number of passes and, thereby, the magnitude of the respective partial deformations. The magnitude of the partial deformation is one of the most important factors which affect the final properties of the wire [6 - 12]. The aim of this paper is to chart the development of the microstructure and mechanical properties of eutectoid steel for the cold drawing of wire with various partial deformation, and thereby to determine to what degree partial deformation impacts the deformation behaviour and hardening of the pearlite microstructure.

2. DESCRIPTION OF THE EXPERIMENT

2.1. Material

The experimental material was a drawn and patented 3.4 mm diameter wire from C78DP steel, the composition of which is provided in **Table 1**. Its microstructure consisted of lamellar and a small amount (up to 2 %) of upper bainite. The wire was pickled and its surface was coated with a lubricant carrier.

Table 1 Chemical composition of the steel examined (wg. %)

C	Mn	Si	P	S	Cu	Ni	Cr
0.79	0.63	0.20	0.010	0.014	0.04	0.02	0.05

2.2. Wire Drawing

The wire was drawn from the diameter of 3.4 mm to 1.5 mm using a 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. The total reduction was 80.5 %. The drawing speed was approximately 1 m/s. The WC drawing dies had an approach angle of 8°. The lubricant used was a commercial Condat 3T hard soap-based grade with an addition of lubricant carrier. Two pass schedules were used, as defined in **Table 2**.

Table 2 Overview of pass schedules

*Standard pass schedule: **7 passes** (average single-pass reduction = 20.8 %)*									
Pass number		0	1	2	3	4	5	6	7
Wire diameter	(mm)	3.4	3	2.7	2.4	2.15	1.9	1.7	1.5
Reduction	(%)		22.1	19.0	21.0	19.7	21.9	19.9	22.1
*Non-standard pass schedule: **5 passes** (average single-pass reduction = 27.9 %)*									
Pass number		0	1	2	3	4	5		
Wire diameter	(mm)	3.4	2.9	2.45	2.1	1.75	1.5		
Reduction	(%)		27.2	28.6	26.5	30.6	26.5		

2.3. Wire Testing

Following each pass, a 10-kg sample of wire was removed from the stock for subsequent testing. Then, 10 test pieces with a 60-cm length were made from this sample coil for a torsion test and 10 test pieces with a 22-cm length were made for a reverse bending test. Prior to testing, the test pieces were straightened by hand.

Torsion testing was carried out in a ZKZE 02/5 machine according to ISO 7800 Metallic materials - Wire - Simple torsion test [13]. As the test pieces had diameters between 3.40 and 1.5 mm, the standard permitted a simplified method of setting the test piece length of 100 times its diameter. In line with the standard, the speed was 50 rpm. The bending test was carried out using a ZOZP 02/5 machine according to ISO 7801 Metallic materials - Wire - Reverse bend test [14].

3. DISCUSSION OF RESULTS

3.1. Metallographic analysis

A metallographic analysis of the wire axis area was conducted using scanning electron micrographs (SEM). A total of 10 photographs were taken of each specimen, using a 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.

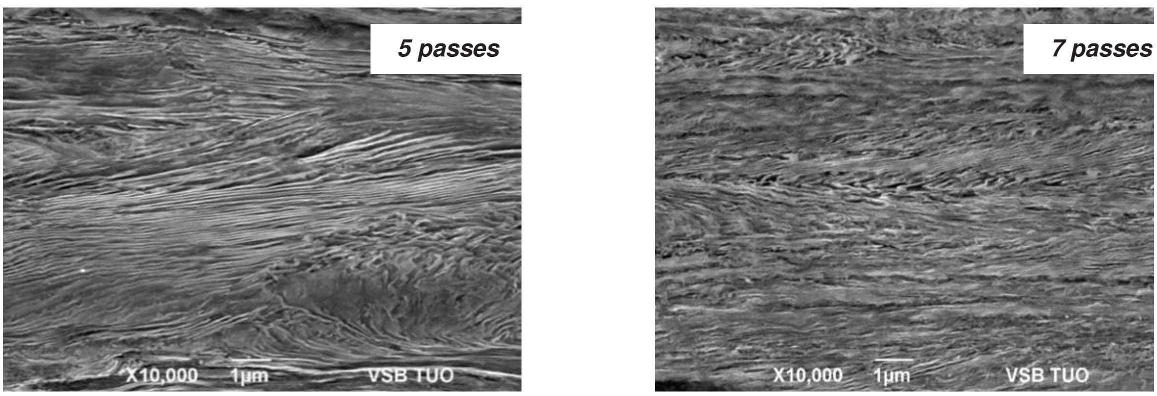


Figure 1 Micrographs of wire upon the last passes (*d* = 1.5 mm) for both drawing schedules, which represent those pearlite colonies that turned in the drawing direction during deformation

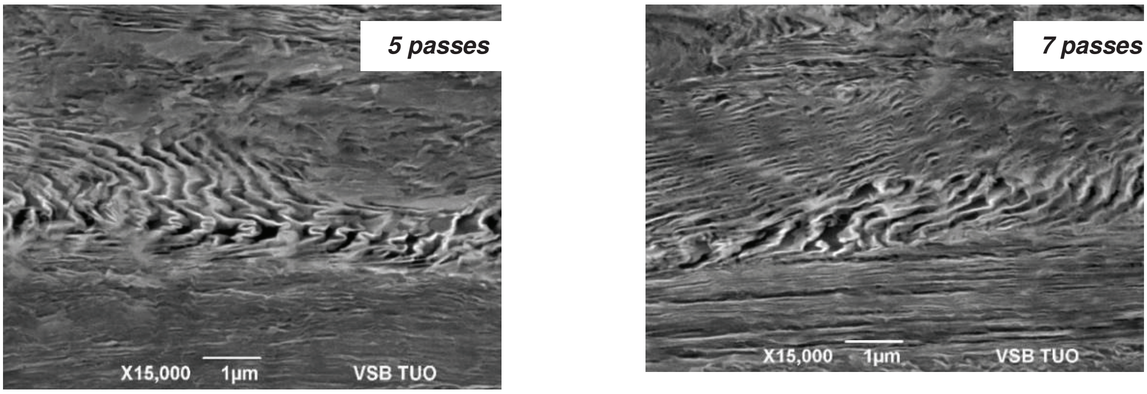


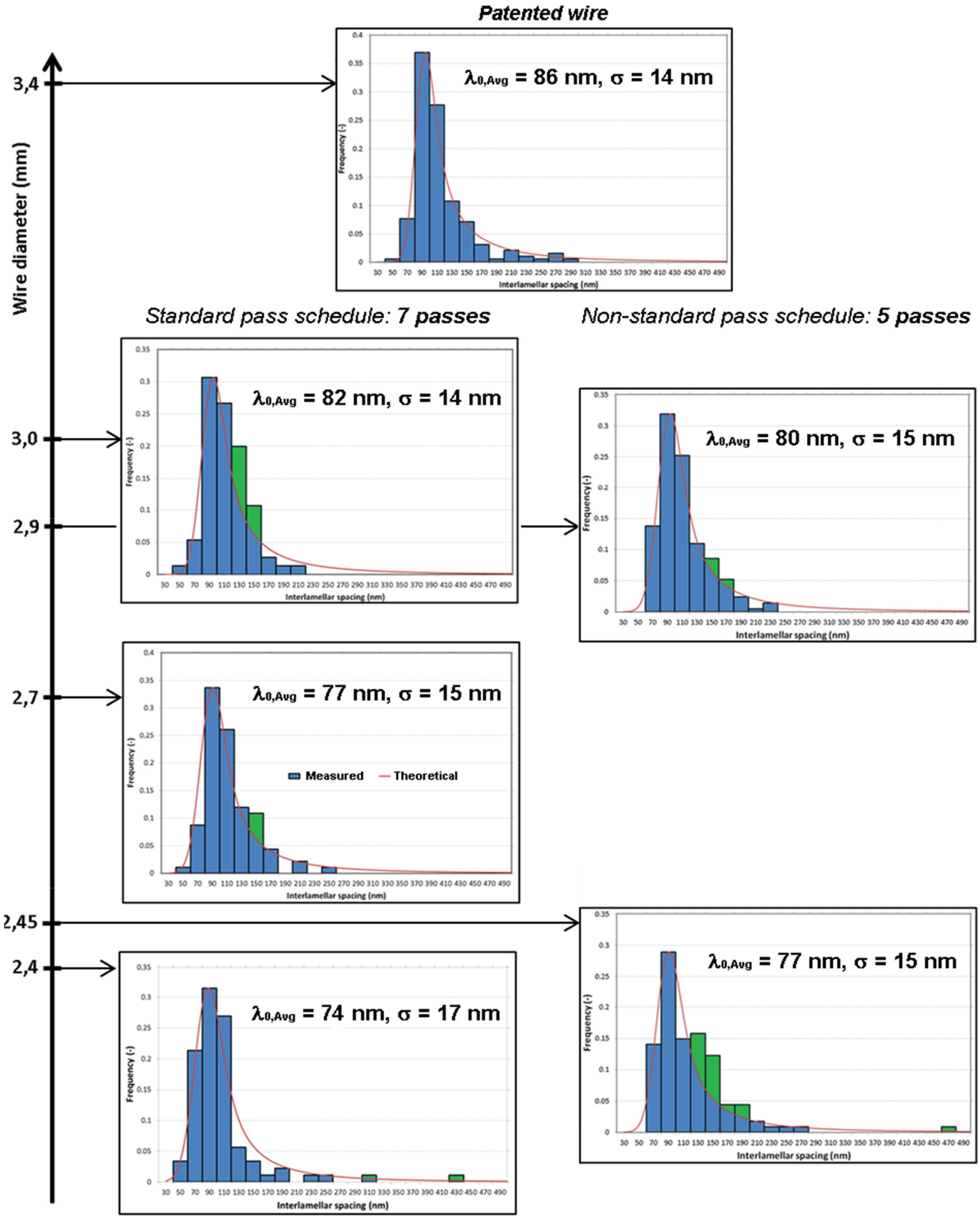
Figure 2 Micrographs of wire upon last passes (d = 1.5 mm) for both drawing schedules, which represent those pearlite colonies that were oriented perpendicular to the drawing direction at the beginning of drawing

Microstructures obtained for both drawing schedules are shown in **Figure 1** and **Figure 2.** In **Figure 1** we see a comparison of pearlite colonies which form the majority of the structure. They are those colonies whose lamella have turned into the direction of drawing during the drawing process, which enabled the maximum reduction of the true interlamellar spacing (TIS) (the minimum TIS values are around 50 nm). On the contrary, **Figure 2** shows less typical colonies, whose lamella were oriented perpendicular of the drawing direction at the beginning of the drawing process, and during drawing these lamella were bent and sometimes even broken. High TIS values are typical for these colonies, where TIS values can even exceed 350 nm.

Using the methodology described in [1] we determined the average TIS values which are summarized in **Table 3**. The values in **Table 3** for the respective pass schedules do not differ significantly, therefore we prepared a comparison of histograms representing the distribution of IS for the respective passes for both pass schedules (see **Figure 3**). In the histograms, the green columns show the frequencies, which do not correspond to the presumption of the random distribution of IS values and the random orientation of lamellas to the direction of drawing. From **Figure 3** it is clear that during drawing a part of the colonies does not turn into the direction of drawing and rather the interlamellar spacing increases due to the bending of lamellas. We want to focus on these colonies to find differences in the behaviour of steel when using partial reductions of varying magnitude. If we compare the character of the histograms for the respective passes, we see a rather significant difference for comparable diameters d_3 = 2.4 mm (7 passes) and d_2 = 2.4 mm (5 passes), where it seems that greater partial deformations cause more substantial quantities of colonies with interlamellar spacing about 1.5 times greater than average. In the following chapter we shall look at the consequences of this fact.

Table 3 Measured true interlamellar spacing of pearlite

*Standard pass schedule: **7 passes** (average single-pass reduction = 20.8 %)*									
Wire diameter		3.4	3	2.7	2.4	2.15	1.9	1.7	1.5
Average of true IS	(nm)	86	82	77	74	77	77	65	62
Standard deviation of true IS	(nm)	12	14	15	17	14	14	14	14
*Non-standard pass schedule: **5 passes** (average single-pass reduction = 27.9 %)*									
Wire diameter		3.4	2.9	2.45	2.1	1.75	1.5		
Average of true IS	(nm)	86	80	77	76	70	62		
Standard deviation of true IS	(nm)	12	15	15	16	16	14		


Patented wire
λ0,Avg = 86 nm, σ = 14 nm
Wire diameter (mm)
3,4
3,0
2,9
2,7
2,45
2,4
Standard pass schedule: 7 passes
Non-standard pass schedule: 5 passes
λ0,Avg = 82 nm, σ = 14 nm
λ0,Avg = 80 nm, σ = 15 nm
λ0,Avg = 77 nm, σ = 15 nm
Measured
Theoretical
λ0,Avg = 74 nm, σ = 17 nm
λ0,Avg = 77 nm, σ = 15 nm
Frequency (-)
Interlamellar spacing (nm)

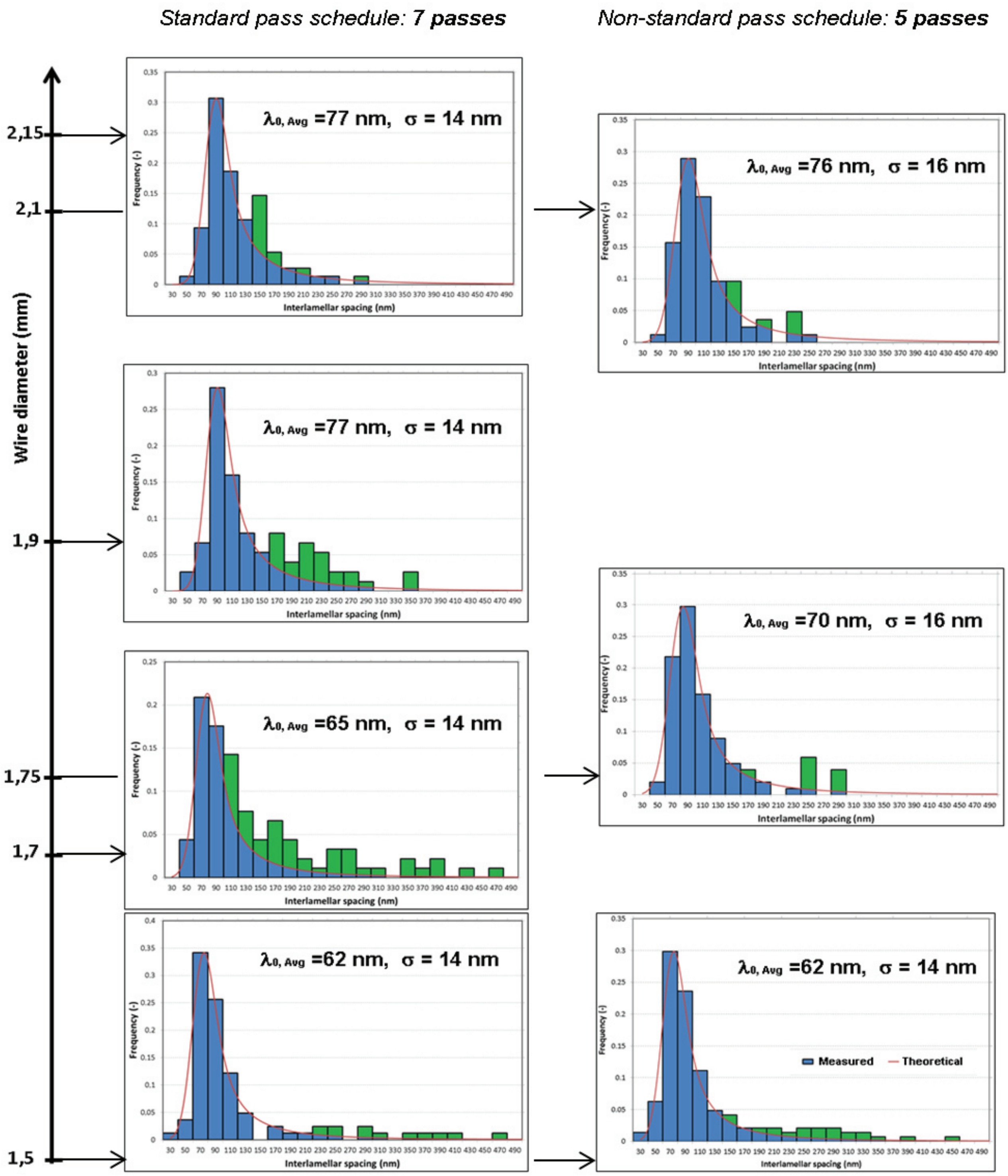


Figure 3 Comparison between histograms constructed from measured data and theoretical relative frequences for the initial wire diameter d_0 and wire diameters upon each of the passes of both pass schedules, Standard (on the left) and Non-standard (on the right). In the green columns, the frequencies are higher than theoretical.

3.2. Effect of varying distribution of interlamellar spacing on the mechanical properties of wire

In the preceding subchapter we mentioned the different distribution of interlamellar spacing for wire with a total deformation approaching 50 % (after the third or second pass in the seven or five pass schedule respectively). This difference manifested slightly in the tensile strength value, where the tensile strength is about 30 MPa higher after the 5 pass schedule than for the standard 7 pass schedule. However, the percentage difference is only about 2 %. This difference has a much greater impact on the shear strain to fracture value (see **Figure 4**). For the 5 pass schedule the shear strain to fracture median value is almost 1.8x greater than for the 7 pass schedule when considering accumulated deformation around 50 %. By using greater partial reductions, we attained a substantially tougher material. This is also confirmed by the number of bends to fracture which was 15 % better than in the case of the 5 pass schedule.

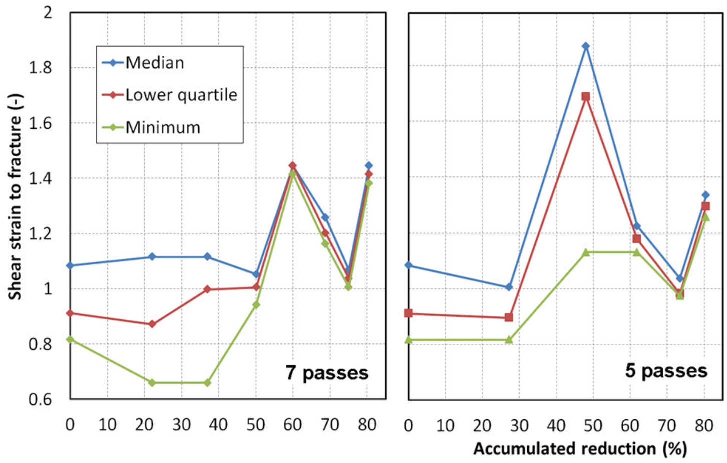


Figure 4 Evolution of shear strain to fracture during drawing in various pass schedules

4. CONCLUSIONS

The market forces steel wire rope producers to achieve ever growing strength parameters and, at the same time, requiring maximum toughness and fatigue resistance. Hence, it is so important to search for a relationship between the drawing technology and resultant wire properties. In this paper we presented an experiment whose aim was to describe the effect of partial deformation. Besides mechanical properties we focused on the microstructural factors of pearlite and their development during drawing. The presented methodology of evaluating IS using histograms representing the distribution of measured IS values enabled us to better describe the impact of the technology on a change in a drawn wire´s microstructure. For assessment purposes we selected the central areas of the wire, but next time we will focus on the surface layers, where we expect a much greater impact of intensive shear deformation which we described in greater detail in [15].

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