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TILECAL-NO-xxx
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Steel absorbers for the Hadronic Tile Calorimeter of the ATLAS Experiment

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Abstract

In this note the measurements and quality control checks on the steel absorbers for the Hadronic Tile Calorimeter of the ATLAS detector are reviewed. In total 41658 sheets of 4.05 mm thickness and 40800 sheets of 5.00 mm thickness were produced and accepted.

1 Introduction

The steel for the absorbers of the hadronic tile calorimeter of the ATLAS detector is produced in the following steps.
Hot rolled coils are used as the incoming material. The thickness is about 5.5 mm, the weight of the coil is 2 – 2.5 tons. One melt is 120 – 220 tons. The Czech standard for the steel is CSN 11375.28 (equivalent to EN 10025).
In the Cold Rolling Mill the first step is acid pickling in 17% HCl at 60° C. Then follows neutralization, washing (2 sections) and drying by hot air. The next step is rolling: for type A (5 mm) annealing and smoothing-rolling; for type B (4.05 mm) rolling with the reduction each pass of 20%, annealing and smoothing-rolling. The recrystallization annealing is performed in the continuous annealing furnace in 6 sections at a temperature of 650 – 800° C in an atmosphere 96% N, 1.5 – 3% H. Two coils pass through the furnace together with a speed of 5.1 m/hour. The whole cycle takes approximately 14 hours (heating, annealing at the given temperature, cooling).
The cold rolling process runs in Králův Dvůr (Czech Republic), where also the type B sheets are cut. The B type sheets are shipped to Dubnica nad Váhom (Slovakia) and Minsk (Belarus). The type A material is sent to Vítkovice (Czech Republic) as coils, where it is cut into sheets. These are then transported to Kopřivnice (Czech Republic) for further processing (punching).

2 The order

After the successful tender sent out by CERN, the order for the supply of laminated steel sheets as absorbers for the ATLAS hadronic tile calorimeter [1] was placed in the Cold Rolling Mill in Králův Dvůr near Prague. The same company produced the steel absorbers for Module 0 of the tile calorimeter [2].
In accordance with the contract, the following quantities of absorbers were ordered:

A. 40800 sheets of dimensions 1620 x 400 x 5.00 mm^3,
with the thickness tolerance ± 0.05 mm

B. 41600 sheets of dimensions 1620 x 400 x 4.05 mm^3,
with the thickness tolerance ± 0.04 mm

The required average sheet thickness tolerance is ± 0.025 mm over the whole production and the tolerances in length and width are (+30 -0) mm and (+1.5 -0) mm respectively.
The order for the type B sheets was slightly changed: 29600 sheets of dimensions 1620 x 400 x 4.05 mm^3 and 12000 sheets of dimensions 1620 x 410 x 4.05 mm^3. The reason for this change was the possibility of a better arrangement for the punching of the spacer plates.

Further details and Quality Control Plan are given in the CERN document CERN-IT-2490/PPE/ATL [3].

3 Chemical analysis, identification of each melt

Chemical analysis from the pans (hot rolled coils) was measured in the hot rolling mill, one measurement per melt. The maximum content according to the specification is given in Table 1. Example of the measured values for melt no. 30731 are in Fig. 1.
The steel is killed steel, where the nitrogen content is less then 0.01% (Fig. 2). The content of carbon was measured by two methods. Contents of carbon and sulphur was determined using infra-red absorption, from one gramme of steel filings in a LECO 125 analyser (Fig. 3). Contents of all elements was determined by glow-discharge spectroscopy using LECO GDS spectrometer (Fig. 4a).
The melt number identifies each melt. All the produced sheets came from 18 melts.

4 Complete chemical analysis

The complete chemical analyses were performed in the laboratories of the cold rolling mill. The maximum content from the order is given in Table 1, the results of the measurements for one coil are given in Fig. 4a. The measured values, corresponding average values and RMS are shown in Table 4 for 4.05 mm steel and in Table 5 for 5.00 mm steel. Distribution of Carbon and Manganese content is given in Fig. 4b. In the figure one can see that the average content of Carbon is 0.08% with the precision of 15% (see also Table 4 and Table 5) in agreement with the specification.

5 Surface-state inspection

Surface-state inspection is made visually during the rolling and cutting. Sheets with noticeable defects are excluded, their number is less than 0.4%. The producer, on the basis of surface state, also rejects the first and last turns of each coil.

6 Corrosion protection

The inhibitor oil INCOR is sprayed during the rolling process on the strip. The coil is protected by DAMINOL oil on the surface before shipping to Vítkovice.
The sheets are packed on pallets. Type A sheets are on pallets produced in Vítkovice with approximately 2 tons per pallet. The sheet on top is protected by DAMINOL, the package is wrapped in special paper STAKOR and bound by steel strips.
Type B sheets are on pallets designed by CERN with approximately 2 tons per pallet and the same packing as for the type A.

7 Mechanical properties, structure and inclusion content, roughness, magnetic properties

Mechanical properties, structure and inclusion content, roughness, magnetic properties introduced in the order are given in Table 2.
The results of measurements are shown in Fig. 5, 6, 7 and 8. Magnetic coercitive field was measured in Prague by CERN Industrial Coercimeter. The measured samples were of dimensions $40 \times 75\,\mathrm{cm}^2$, the example of the protocol is given in Fig. 9a. The magnetic properties of the 5 mm steel sheets are quite important. Considerable amount of the return magnetic flux flows through the master plates of the calorimeter. For this reason the carbon content (Fig. 4b) and the intensity of the magnetic coercivity should be as low as technically possible. The values of magnetic coercivity are rather constant, the average value being 217.2 A/m with the precision of 6%, and is below the limits given in the specification (Fig. 9b).

8 Thickness measurements and dimensions

The thickness was measured on one sheet (reference sheet) out of each pallet, in 9 points according to the CERN document CERN-IT-2490/PPE/ATL [3]. The thickness was measered with a calibrated MITUTOYO micrometer on line with a PC. The overall mean thickness is given in Table 3 from all the sheets tested.
The results of thickness measurements are given in Fig. 10 and 11. The individual measured values of mean thickness for each reference sheet lie within the limit ± 0.025 mm. If the points on a reference sheet were measured to be out of tolerances during the acceptance process, the sheet was excluded and then futrher five sheets (approx. every fifth in the sequence) were measured. The average thickness of the whole measured sample was calculated and if within tolerances, the pallet was accepted, with exclusion of the sheets outside the torerance limits. In Fig. 11a and 11b the points lying out of tolerances represent the "bad" reference sheets, which were then excluded in the acceptance procedure. The corrected

thickness values for the remeasured pallets are not shown in these figures. However, for the type A (5 mm) about 0.5% of pallets and for type B (4.05 mm) less then 2% of pallets respectively were not accepted since the mean thickness was in most cases too low.
Furthermore of type A 191 sheets were excluded because of scratches and "double layer" and 32 were not accepted because of damage during the transport from Vítkovice to Kopřivnice.
The wedge shape, which is rather important for the master plates was also measured and the mean value for the 5 mm sheets is 0.020 mm with RMS of 0.015 mm. The measured values of dimensions are displayed in Fig. 12. The values lie in the limits given in the order. The overall measured thickness for 4.05 mm sheets is (4.041±0.014) mm and for 5.00 mm sheets is (4.993±0.017) mm in agreement with the specification.

9 Planarity

Measuring the longitudinal and border sagitta checked the planarity. The maximum acceptable values are 2 mm and 4 mm respectively. The measured values are in the acceptance limits. The results of measurements for the 5 mm steel are given in Fig. 13. For the 4.05 mm steel the values are similar, but the measurements were not recorded, because for the small spacers, the values are not as critical.

10 Internal stress

The test sheets were carefully cut and the sides put one to the other (see CERN method [3]). No measurable space between the cut sides has been observed.

11 Conclusions

The quality of the accepted sheets of the steel produced by the Cold Rolling Mill in Králův Dvůr corresponds to the quality requirements given in the CERN order. The results of quality control and corresponding measurements are given in Table 4 and 5.

References

[1] *ATLAS Internal Note*, TILECAL-NO-121, Supply of laminated steel sheets as absorber for the ATLAS Tile Hadron Calorimeter, Call for tenders IT-2490/PPE/ATL, 30 June 1997

[2] *ATLAS Internal Note*, TILECAL-NO-098, T. Davídek et al., The Procurement of the steel for the TILECAL barrel module 0, 9 November 1996

[3] Supply of laminated Steel Sheets as Absorber for the ATLAS Tile Hadron Calorimeter, CERN-IT-2490/PPE/ATL, Quality Control Plan, January 1998

Figure captions

Fig. 1 Example of the attestation of the chemical analysis of the hot rolled strip.

Fig. 2 Example of the attestation of the nitrogen content.

Fig. 3 Example of the attestation of the carbon content in the hot rolled strip.

Fig. 4 (4a) Example of the attestation of the chemical analysis of the cold rolled sheets; (4b) distribution of carbon and manganese contents for 4.05 mm and 5 mm steel.

Fig. 5 Mechanical properties of the cold rolled sheets. (5a) Examples of the measured values of σ_{max} (tensile strength), $\sigma_{y0.2}$ (yield strength) and A_{80} (strain to failure). The curve shows the dependence of the relative elongation ϵ on applied force F for the type A sheets (5 mm).
Distribution of tensile properties for 4.05 mm and 5 mm steel (5b) and strain to failure for 4.05 mm and 5 mm steel (5c).

Fig. 6 Example of the attestation of impact strength measurements for 4.05 mm (6a) and 5 mm steel (6b) respectively. Corresponding distribution of impact strength measurements for 4.05 mm and 5 mm steel (6c).

Fig. 7 Examples of the structure (grain size) and inclusion content for 4.05 mm (7a) and 5 mm steel (7b) respectively and corresponding distributions (7c)

Fig. 8 (8a) Example of the roughness profile (x-axis 1 div = 250 μm ; y-axis 1 div = 5 μm). Distribution of average roughness for 4.05 mm and 5 mm steel (8b).

Fig. 9 (9a) Example of the protocol of magnetic coercivity measurements and its distribution for 4.05 mm and 5 mm steel (9b).

Fig. 10 Example of the protocol of the on-line thickness measurements during the cold rolling.

Fig. 11 Results of the thickness and wedgeness measurements for the 4.05 mm steel (11a) and for the 5 mm steel (11b) respectively. Hatched area represent the measured reference sheets which are out of tolerances.

Fig. 12 Results of the dimensional measurements for 4.05 mm steel (12a) and for 5 mm steel (12b) respectively.

Fig. 13 Results of measurements of the longitudinal and border sagitta for the 5 mm steel.

Element	Order
C	0.17%
Mn	1.00%
P	0.055%
S	0.055%
N	0.011%

Table 1: Maximum content of elements from the technical specification.

Quantity	Order
Tensile strength (σ_{max})	min 340 MPa
Yield strength ($\sigma_{y0.2}$)	min 235 MPa
Strain to failure (A_{80})	min 26 %
Impact strength	min 28 J/cm^2
Grain size	max 50 μm
Inclusions	max class 3
Average roughness	max 12.5 μm
Magnetic coercivity	max 250 A/m

Table 2: Requested mechanical and magnetic properties.

Mean thickness (mm)	Sheets type A	Sheets type B
Order	5.000 ± 0.025	4.050 ± 0.025
Measured	4.993 ± 0.017	4.041 ± 0.014

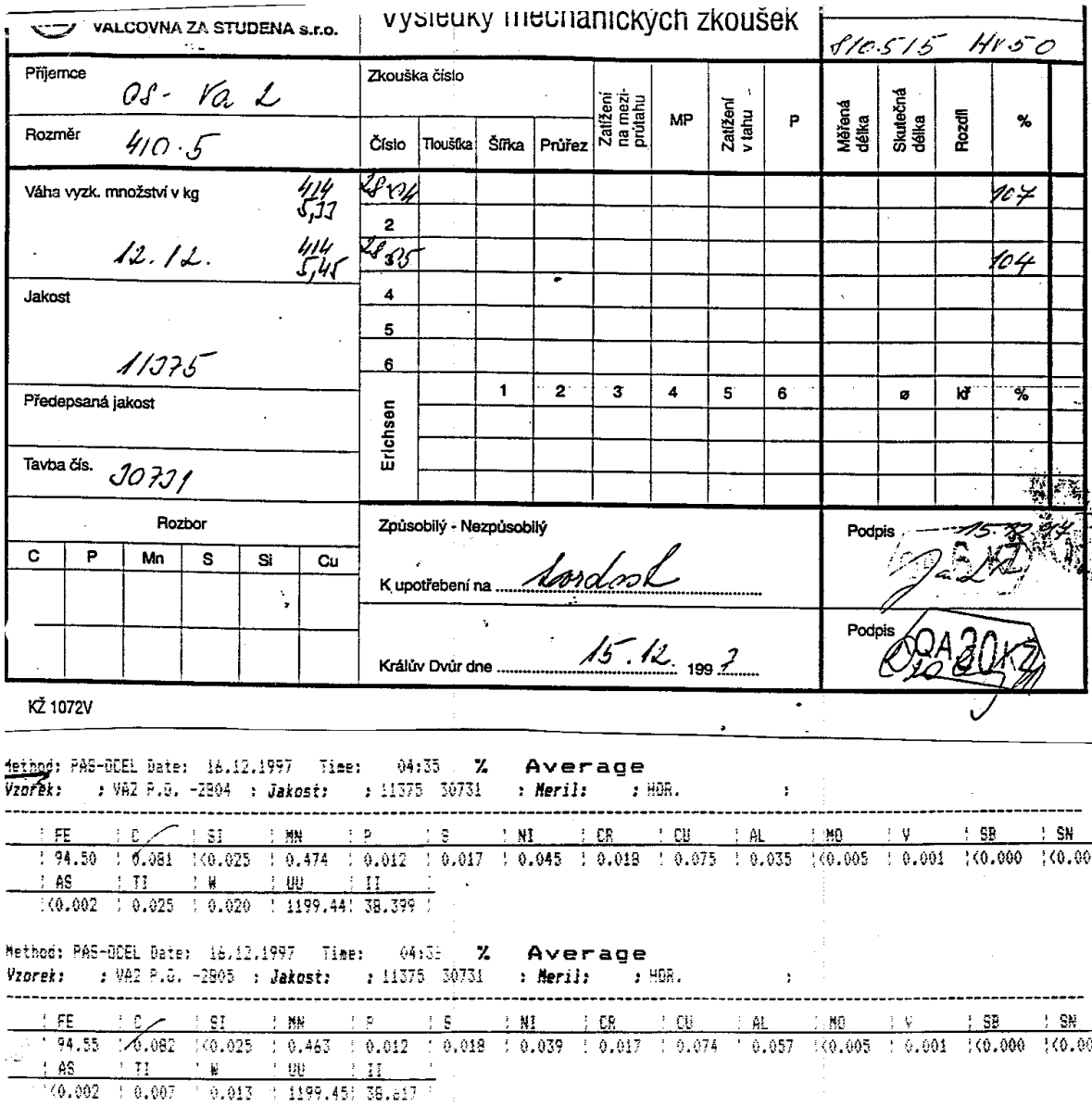
Table 3: Mean thickness measurement.

Thickness 4.05 mm	Melt	C %	N %	P %	S %	Mn %	σ_{max} MPa	$\sigma_{y0.2}$ MPa	A_{80} %	Impact J/cm^2	Grain size max.	Inclusions class	Roughness μm	Mag.coer. A/m
1	30713	0.100	<0.009	0.012	0.017	0.516	364	259	29.5	49.85	37.4	1	1.14	195.7
2	30748	0.089	<0.009	0.012	0.017	0.456	347	266	33.2	49.85	37.8	0.5	0.50	
3	32286	0.095	<0.009	0.011	0.013	0.494	348	246	30.4	30.55	44.9	1–2	0.40	147.0
4	32471	0.057	<0.009	0.011	0.008	0.514	343	253	33.5	47.78	63.5	1–2	0.38	229.4
5	32475	0.080	<0.009	0.011	0.010	0.459	420	275	34.1	28.89	63.5	2	0.29	133.9
6	32557	0.072	<0.009	0.013	0.012	0.450	361	279	28.7	61.11	63.5	2–3	0.35	
7	32966	0.073	<0.009	0.015	0.011	0.438	358	261	29.1	72.80	63.5	2	0.19	135.0
8	32966	0.073	<0.009	0.015	0.011	0.438	358	261	29.1	39.16	63.5	2	0.19	
9	32969	0.068	<0.009	0.014	0.009	0.443	317	211	40.1	56.40	22.5	1–2	0.27	226.9
10	32975	0.076	<0.009	0.011	0.010	0.439	369	276	29.6	67.80	44.9	2	0.34	166.2
11	32975	0.076	<0.009	0.011	0.010	0.439	369	276	29.6	77.78	44.9	2	0.34	
12	32981	0.091	<0.009	0.010	0.014	0.396	349	268	28.4	32.77	63.5	1–2	0.50	
13	32985	0.079	<0.009	0.011	0.009	0.424	389	276	31.3	71.10	44.9	2–3	0.25	220.4
14	32985	0.079	<0.009	0.011	0.009	0.424	389	276	31.3	71.10	63.5	2–3	0.25	220.4
15	32985	0.079	<0.009	0.011	0.009	0.424	389	276	31.3	36.94	63.5	2–3	0.25	
16	34333	0.089	<0.009	0.013	0.009	0.437	333	241	33.5	73.89	63.5	2–3	0.23	164.1
17	34339	0.080	<0.009	0.013	0.007	0.398	357	279	29.5	71.28	22.5	2–3	0.40	135.0
18	34339	0.088	<0.009	0.012	0.013	0.477	406	326	26.9	71.28	44.9	1–2	0.25	135.0
19	34339	0.088	<0.009	0.012	0.013	0.477	406	326	26.9	77.22	63.5	2–3	0.25	135.0
20	34343	0.106	<0.009	0.014	0.011	0.397	340	242	34.4	74.84	22.5	2–3	0.33	135.0
21	34348	0.075	<0.009	0.011	0.009	0.554	356	276	32.4	60.37	18.9	1	0.38	218.5
22	34348	0.075	<0.009	0.011	0.009	0.554	356	276	32.4	77.22	63.5	1–2	0.38	218.5
23	35568	0.096	<0.009	0.013	0.016	0.397	418	293	27.1	74.84	22.5	1–2	0.49	
24	35568	0.096	<0.009	0.013	0.016	0.397	418	293	27.1	74.84	22.5	1–2	0.49	235.6
25	35568	0.062	<0.009	0.013	0.016	0.406	341	274	37.1	74.84	22.5	3	0.39	235.6
26	35568	0.096	<0.009	0.013	0.016	0.397	418	293	27.1	74.84	22.5	1–2	0.49	235.6
27	35568	0.062	<0.009	0.013	0.016	0.406	341	274	37.1	74.84	22.5	3	0.39	235.6
Mean		0.081	<0.009	0.012	0.012	0.438	369	272	31.1	62.01	44.3		0.37	187.9
RMS		0.012		0.001	0.003	0.036	29	23	3.4	16.05	17.8		0.18	42.4

Table 4: Quality control for 4.05 mm steel.

Thickness 5.00 mm	Melt	C %	N %	P %	S %	Mn %	σ_{max} MPa	$\sigma_{y0.2}$ MPa	A_{80} %	Impact J/cm^2	Grain size max.	Inclusions class	Roughness μm	Mag.coer. A/m
1	30731	0.090	<0.009	0.014	0.017	0.440	372	264	36.6	45.93	18.9	1	0.49	
2	30748	0.100	<0.009	0.015	0.018	0.408	359	264	35.5	69.48	18.9	1	0.56	232.2
3	32286	0.083	<0.009	0.010	0.012	0.512	369	289	34.8	78.34	44.9	1–2	0.32	240.6
4	32286	0.083	<0.009	0.010	0.012	0.512	369	289	34.8	78.34	44.9	1–2	0.32	240.6
5	32288	0.085	<0.009	0.010	0.006	0.520	351	242	36.9	72.22	22.5	1–2	0.49	230.3
6	32288	0.085	<0.009	0.010	0.006	0.520	351	242	36.9	72.22	22.5	1–2	0.49	230.3
7	32288	0.085	<0.009	0.010	0.006	0.520	351	242	36.9	72.22	22.5	1–2	0.49	230.3
8	32471	0.077	<0.009	0.013	0.014	0.438	352	300	33.4	63.89	22.5	2–3	0.32	200.7
9	32471	0.077	<0.009	0.013	0.014	0.438	352	300	33.4	63.89	22.5	2–3	0.32	200.7
10	32471	0.077	<0.009	0.013	0.014	0.438	352	300	33.4	63.89	22.5	2–3	0.32	200.7
11	32475	0.064	<0.009	0.011	0.014	0.464	351	269	30.6	72.77	22.5	2–3	0.38	211.0
12	32475	0.064	<0.009	0.011	0.014	0.464	351	269	30.6	72.77	22.5	2–3	0.38	211.0
13	32475	0.064	<0.009	0.011	0.014	0.464	351	269	30.6	72.77	22.5	2–3	0.38	211.0
14	32557	0.060	<0.009	0.012	0.013	0.468	341	258	32.4	72.78	22.5	1–3	0.37	209.1
15	32557	0.060	<0.009	0.012	0.013	0.468	341	258	32.4	72.78	22.5	1–3	0.37	209.1
16	32557	0.060	<0.009	0.012	0.013	0.468	341	258	32.4	72.78	22.5	1–3	0.37	209.1
17	32966	0.087	<0.009	0.010	0.011	0.433	359	263	35.9	72.80	31.8	1	0.55	216.8
18	32966	0.087	<0.009	0.010	0.011	0.433	359	263	35.9	72.80	31.8	1	0.55	216.8
19	32969	0.069	<0.009	0.013	0.009	0.440	348	303	33.6	68.35	22.5	2–3	0.55	209.7
20	32969	0.069	<0.009	0.013	0.009	0.440	348	303	33.6	68.35	22.5	2–3	0.55	209.7
21	32981	0.089	<0.009	0.009	0.011	0.409	349	239	38.4	73.89	22.5	1–2	0.24	224.1
22	32981	0.089	<0.009	0.009	0.011	0.409	349	239	38.4	73.89	22.5	1–2	0.24	224.1
23	32985	0.117	<0.009	0.014	0.015	0.395	362	271	34.8	73.35	15.9	2–3	0.52	199.7
24	34343	0.079	<0.009	0.013	0.005	0.513	361	237	41.1	74.80	15.9	2–3	0.56	
25	34348	0.070	<0.009	0.015	0.004	0.586	352	263	33.8	77.22	22.5	2–3	0.83	225.1
26	34348	0.070	<0.009	0.015	0.004	0.586	352	263	33.8	77.22	22.5	2–3	0.83	225.1
27	35568	0.070	<0.009	0.012	0.014	0.433	359	242	35.3	74.83	15.9	1–2	0.69	211.9
Mean		0.078	<0.009	0.012	0.011	0.458	354	267	34.7	71.28	23.9		0.46	217.2
RMS		0.013		0.002	0.004	0.038	8	21	2.5	6.27	6.9		0.15	12.1

Table 5: Quality control for 5.00 mm steel.



VALCOVNA ZA STUDENA s.r.o.

Výsledky mechanických zkoušek

410.515 HV50

Příjemce: OS - Val

Rozměr: 410.5

Váha vyzk. množství v kg: 414 5,33 / 414 5,45

12.12.

Jakost: 11375

Předepsaná jakost:

Tavba čís.: 30731

Zkouška číslo	Číslo	Tloušťka	Šířka	Průřez	Zatížení na mezi-průtahu	MP	Zatížení v tahu	P	Měřená délka	Skutečná délka	Rozdíl	%
	1											107
	2											
	3											104
	4											
	5											
	6											
Erichsen		1	2	3	4	5	6		ø	kř	%	

Rozbor

C	P	Mn	S	Si	Cu

Způsobilý - Nezpůsobilý

K upotřebení na: Lodosk

Králův Dvůr dne: 15.12. 199 7

Podpis: 15.12.94

Podpis: QA 30 K

KŽ 1072V

Method: PAS-DCEL Date: 16.12.1997 Time: 04:35 % Average

Vzorek: : VA2 P.Ú. -2904 : Jakost: : 11375 30731 : Meril: : HDR. :

FE	C	SI	MN	P	S	NI	CR	CU	AL	MO	V	SB	SN
94.50	0.081	<0.025	0.474	0.012	0.017	0.045	0.018	0.075	0.035	<0.005	0.001	<0.000	<0.00
AS	TI	W	UU	II									
<0.002	0.025	0.020	1199.44	38.399									

Method: PAS-DCEL Date: 16.12.1997 Time: 04:3 % Average

Vzorek: : VA2 P.Ú. -2905 : Jakost: : 11375 30731 : Meril: : HDR. :

FE	C	SI	MN	P	S	NI	CR	CU	AL	MO	V	SB	SN
94.55	0.082	<0.025	0.463	0.012	0.018	0.039	0.017	0.074	0.057	<0.005	0.001	<0.000	<0.00
AS	TI	W	UU	II									
<0.002	0.007	0.013	1199.45	38.217									

Fig. 1:
Example of the attestation of the chemical analysis.

13. 1. 1998 [400/144

ANALYTICKÁ CHEMIE, AKREDITOVANÁ ZKUŠEBNÍ LABORATOŘ 1047
pod registračním číslem ČIA Praha 109/1996 k chemickým zkouškám materiálů
ŠKODA VÝZKUM s.r.o., Tylova 57, 316 00 Plzeň, ☎019/7732415, fax 019/7733889

PROTOKOL O ZKOUŠKÁCH

Číslo : 685
List číslo : 1
Počet listů : 1

ZÁKAZNÍK : *KRÁLODVORSKÉ ŽELEZÁRNY*
VÁLCOVNA ZA STUDENA s.r.o.
267 01 Králův Dvůr

PŘEDMĚT ZKOUŠEK : *Stanovení dusíku ve vzorcích plechu*

Datum přijetí zkoušek : *9.1.1998*
Datum provedení zkoušek : *12.1.1998*
Zakázkové číslo :
Obědnávka číslo : *219009/84884*

Materiál :
Tavba :
Označení : *vz. č. 1,2,3,4,5,6*
Č. výkresu :

VÝSLEDKY ZKOUŠEK : Lab. číslo : *92 523/28*

Označení	N %	
vz.č. 1	*0,008*	tavba 30 731
vz.č. 2	*0,010*	
vz.č. 3	*0,009*	
vz.č. 4	*0,007*	tavba 30 744
vz.č. 5	*0,008*	
vz.č. 6	*0,008*	

STÁTEM AKREDITOVANÁ ZKUŠEBNÍ LABORATOŘ ŠKODA VÝZKUM s.r.o. 2 1047

V Plzni *12.1.1998*

Vedoucí laboratoře Ing. Jaroslav Čechura

Metody použité pro chemické rozbory jsou uvedeny v Příručce jakosti CHE a splňují požadavky na přesnost dle ČSN EN, ČSN ISO. Uvedené výsledky zkoušek se týkají jen předmětu těchto zkoušek. Protokol může být reprodukován pouze jako celek.

Fig. 2:
Example of the attestation of the nitrogen content.

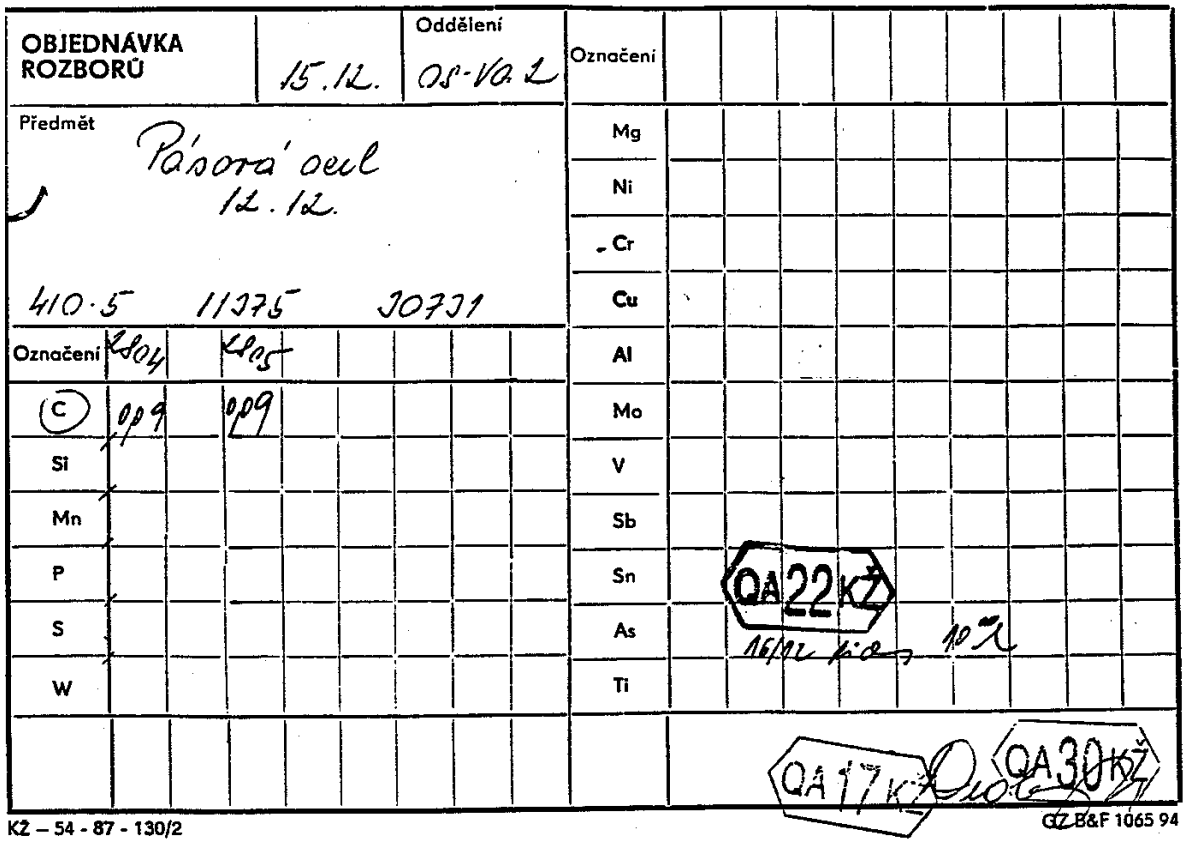
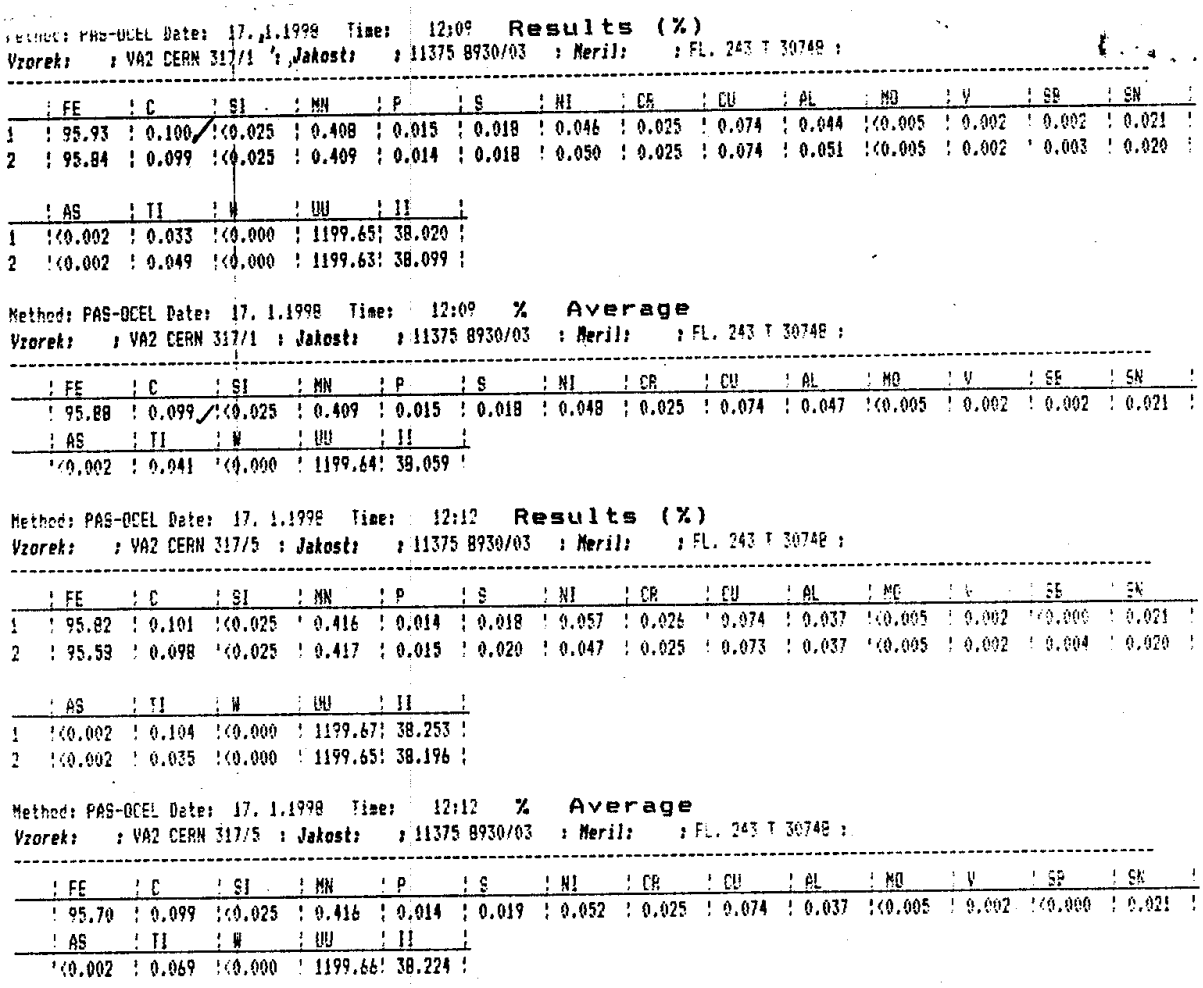


Fig. 3:
Attestation of the carbon content in the hot rolled strip.



Method: PAS-OCEL Date: 17. 1.1998 Time: 12:09 **Results (%)**
Vzorek: : VA2 CERN 317/1 : *Jakost:* : 11375 8930/03 : *Meril:* : FL. 243 T 30748 :

	FE	C	SI	MN	P	S	NI	CR	CU	AL	MO	V	SB	SN
1	95.93	0.100	<0.025	0.408	0.015	0.018	0.046	0.025	0.074	0.044	<0.005	0.002	0.002	0.021
2	95.84	0.099	<0.025	0.409	0.014	0.018	0.050	0.025	0.074	0.051	<0.005	0.002	0.003	0.020

	AS	TI	W	UU	II
1	<0.002	0.033	<0.000	1199.65	38.020
2	<0.002	0.049	<0.000	1199.63	38.099

Method: PAS-OCEL Date: 17. 1.1998 Time: 12:09 **% Average**
Vzorek: : VA2 CERN 317/1 : *Jakost:* : 11375 8930/03 : *Meril:* : FL. 243 T 30748 :

FE	C	SI	MN	P	S	NI	CR	CU	AL	MO	V	SB	SN
95.88	0.099	<0.025	0.409	0.015	0.018	0.048	0.025	0.074	0.047	<0.005	0.002	0.002	0.021

AS	TI	W	UU	II
<0.002	0.041	<0.000	1199.64	38.059

Method: PAS-OCEL Date: 17. 1.1998 Time: 12:12 **Results (%)**
Vzorek: : VA2 CERN 317/5 : *Jakost:* : 11375 8930/03 : *Meril:* : FL. 243 T 30748 :

	FE	C	SI	MN	P	S	NI	CR	CU	AL	MO	V	SB	SN
1	95.82	0.101	<0.025	0.416	0.014	0.018	0.057	0.026	0.074	0.037	<0.005	0.002	<0.000	0.021
2	95.59	0.098	<0.025	0.417	0.015	0.020	0.047	0.025	0.073	0.037	<0.005	0.002	0.004	0.020

	AS	TI	W	UU	II
1	<0.002	0.104	<0.000	1199.67	38.253
2	<0.002	0.035	<0.000	1199.65	38.196

Method: PAS-OCEL Date: 17. 1.1998 Time: 12:12 **% Average**
Vzorek: : VA2 CERN 317/5 : *Jakost:* : 11375 8930/03 : *Meril:* : FL. 243 T 30748 :

FE	C	SI	MN	P	S	NI	CR	CU	AL	MO	V	SB	SN
95.70	0.099	<0.025	0.416	0.014	0.019	0.052	0.025	0.074	0.037	<0.005	0.002	<0.000	0.021

AS	TI	W	UU	II
<0.002	0.069	<0.000	1199.66	38.224

Fig. 4a:
Attestation of the chemical analysis of the cold rolled sheets.

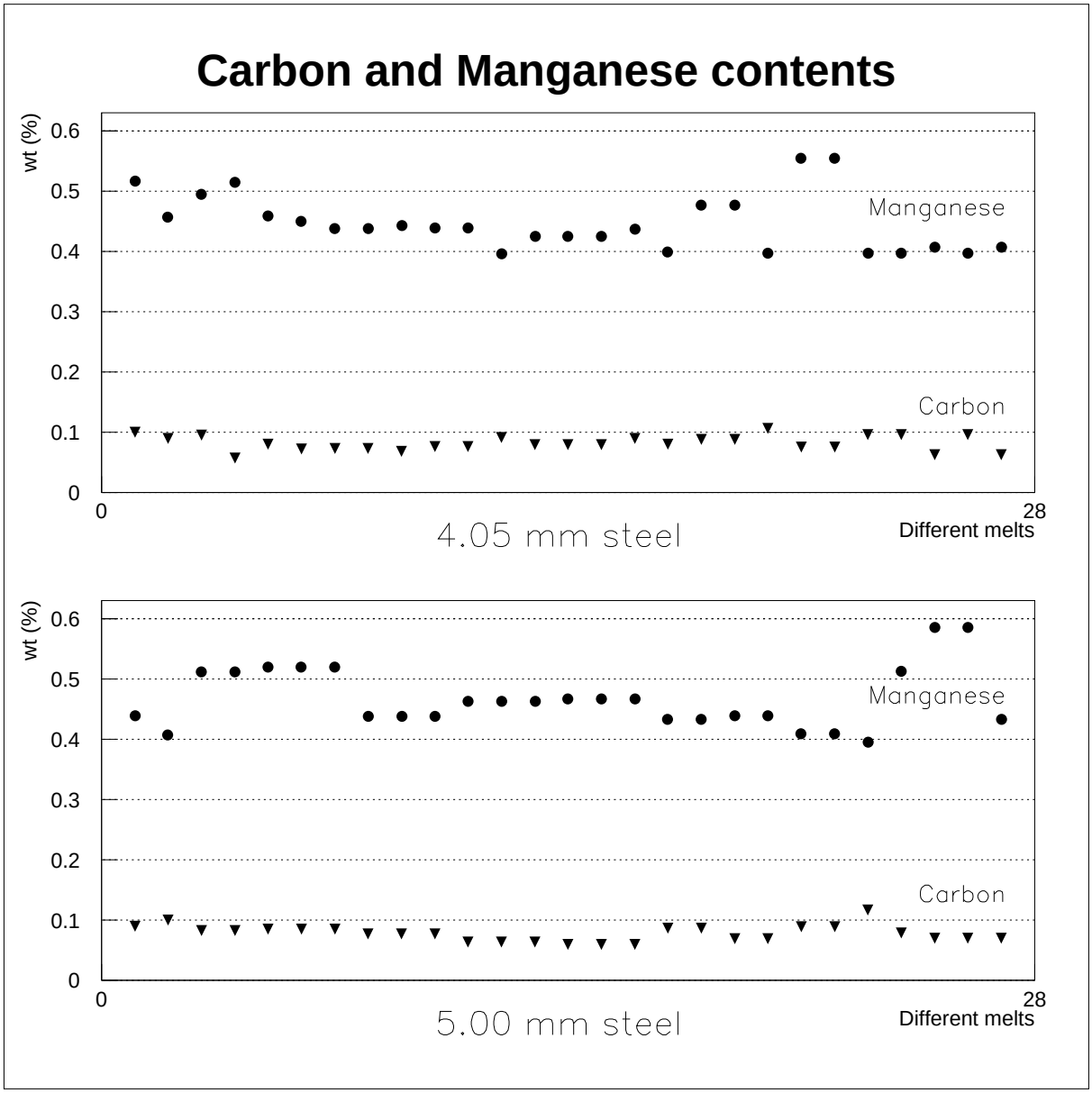


Fig. 4b:
Distribution of Carbon and Manganese contents.

Číslo vzorku: 317 6A Zákazník: CERN 8930/03	18-1-1998 06:44
Rychlost zatěžování: v1 = 5.4 mm/min Původní rozměry: Lo = 80.00 mm 4.99 x 20.00 So = 99.80 mm² Konečné rozměry: L = 108.40 mm	Naměřené parametry: Rp(0.20) = 264 F[kN] = 26.3 Rm[N/mm²]= 359 F[kN] = 35.8 A[%] = 35.5

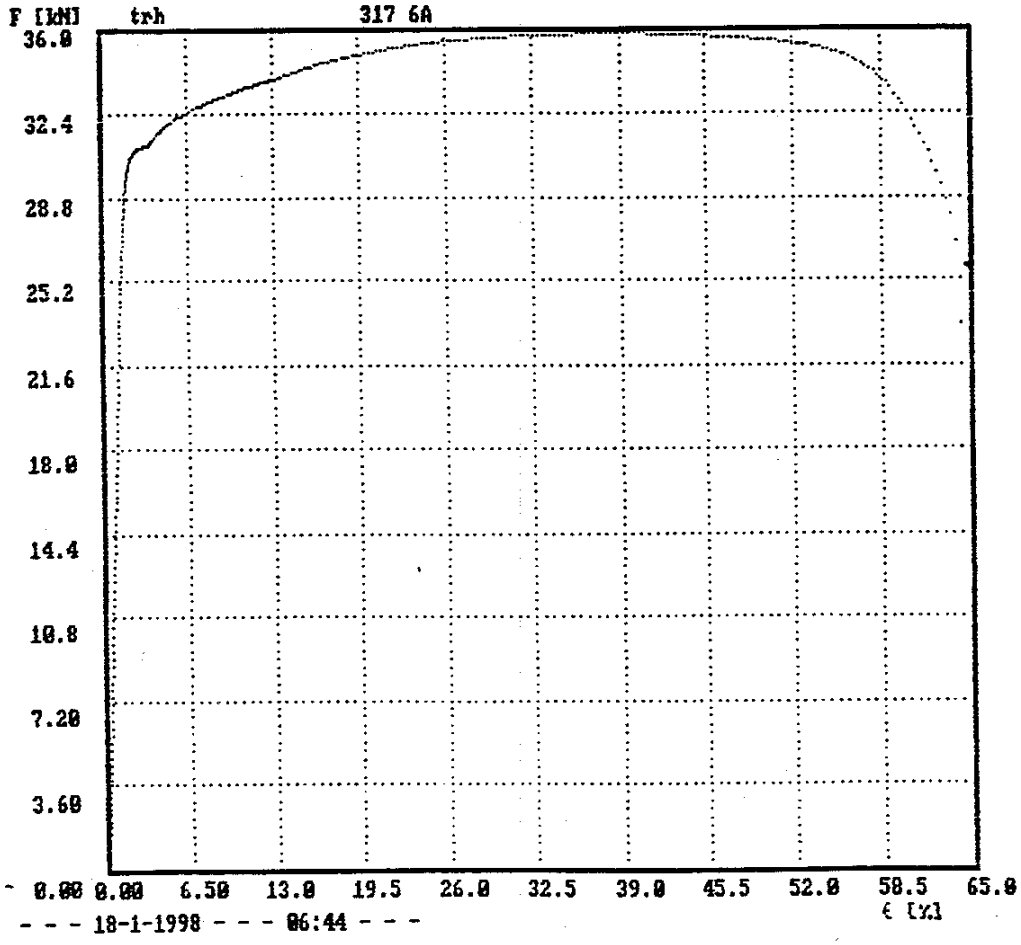


Fig. 5a:
Attestation of mechanical properties measurements.

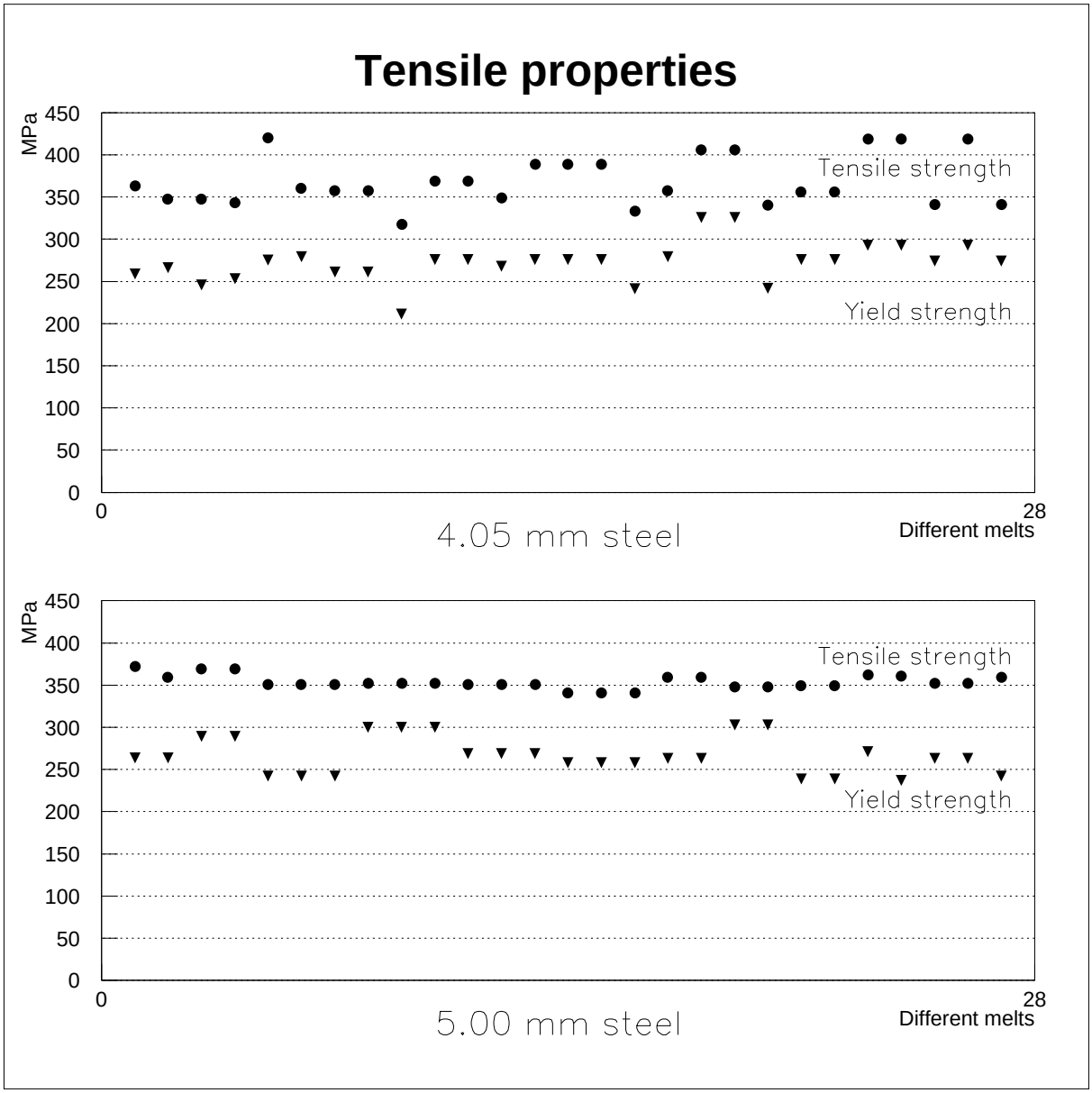


Fig. 5b:
Distribution of tensile properties.

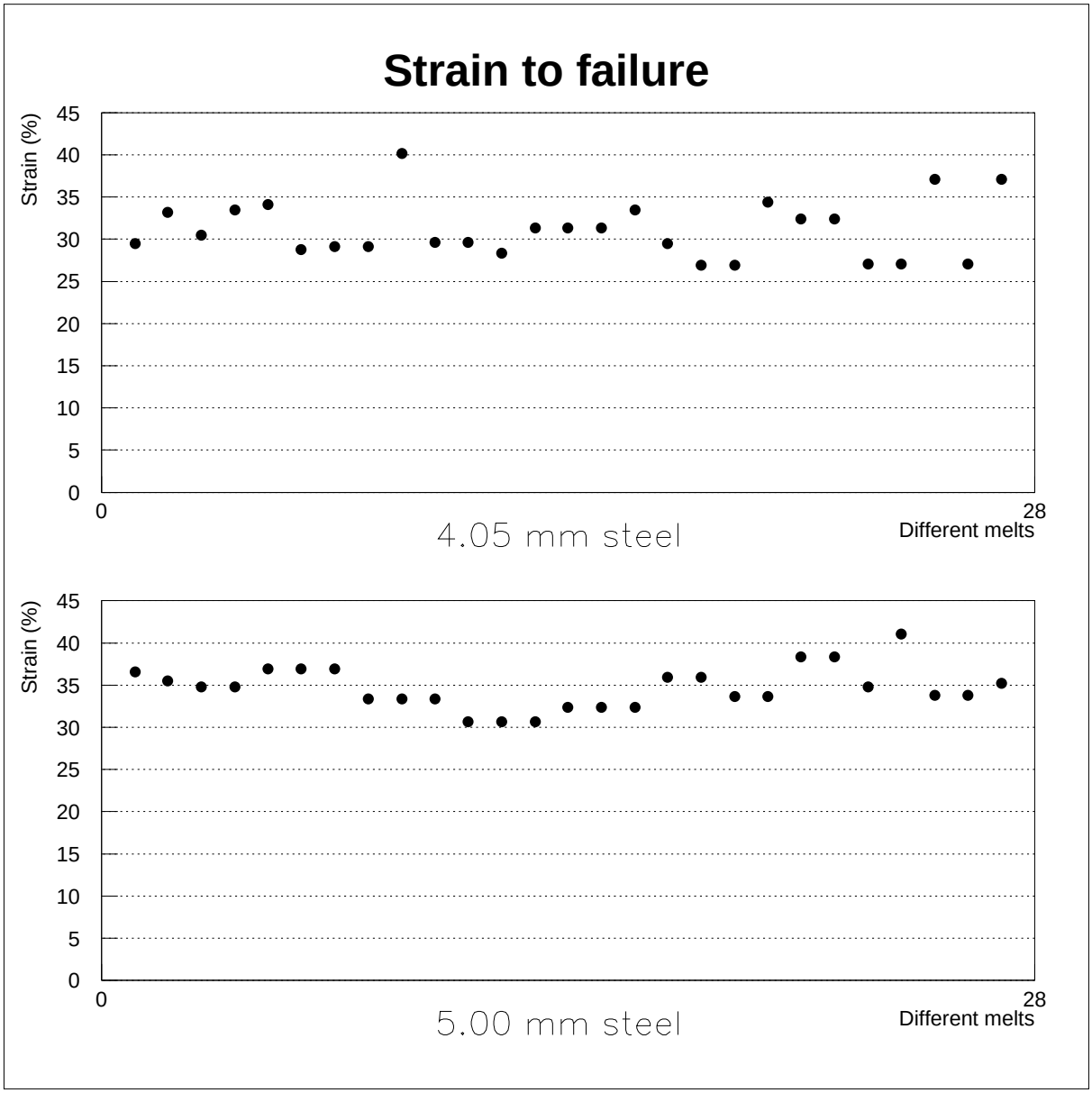


Fig. 5c:
Distribution of strain to failure.

MECHANICKÁ ZKUŠEBNA, státem akreditovaná zkušební laboratoř 1047 pro mechanické zkoušky materiálů, pod reg.č. ČIA Praha 109/1996
ŠKODA VÝZKUM s.r.o., Tylova 57, 316 00 Plzeň, 019/7732904

PROTOKOL O ZKOUŠKÁCH

č. : 132
List : 1
Počet listů : 2

ZÁKAZNÍK : KRÁLOVODVORSKÉ ŽELEZÁRNY

PŘEDMĚT ZKOUŠEK : PLECH
Zakázkové číslo : 015 - 53/390
Datum převzetí : 26.1.1998
Datum zkoušení : 4.2.1998

VÝSLEDKY ZKOUŠEK:

Zkouška rázem v ohybu dle DIN 50 115 vzorky 4 x 3 x 27 - vrub V1

Tloušťka plechu 4 mm - podélný směr			Tloušťka plechu 4 mm - příčný směr		
označení	KV (J)	KCV (J/cm^2)	označení	KV (J)	KCV (J/cm^2)
4,1	7,1	78,89	04.01.00	4,5	50
4,1	8,1	90	04.01.00	4,5	50
4,1	7,5	83,33	04.01.00	5	55,56
4,2	6,6	73,33	04.02.00	5,5	61,11
4,2	6,3	70	04.02.00	4,9	54,44
4,2	6	66,67	04.02.00	5,7	63,33
4,3	7	77,78	04.03.00	3,8	42,22
4,3	4,4	48,89	04.03.00	4,9	54,44
4,3	6,6	73,33	04.03.00	3,5	38,89
4,4	6,8	75,56	04.04.00	4,5	50
4,4	7	77,78	04.04.00	4,6	51,11
4,4	6,7	74,44	04.04.00	4,4	48,89
4,5	4,5	50	04.05.00	3,8	42,22
4,5	4,4	48,89	04.05.00	3,8	42,22
4,5	3,7	41,11	04.05.00	3,9	43,33
Průměr	6,18	68,67	Průměr	4,49	49,85

V Plzni: 4.2.1998

AKREDITOVANÁ ZKUŠEBNÍ LABORATOŘ ŠKODA VÝZKUM s.r.o.

Ing. Václav Mentl, CSc.
vedoucí laboratoře

Uvedené výsledky zkoušek se týkají jen předmětu těchto zkoušek. Veškeré porovnávání naměřených hodnot s hodnotami požadovanými je mimo rámec akreditace dle ČSN EN 45 001. Bez svolení zkušební laboratoře smí být protokol reprodukován pouze jako celek.

Fig. 6a:
Attestation of impact strength measurements for 4.05 mm steel.

MECHANICKÁ ZKUŠEBNA, státem akreditovaná zkušební laboratoř 1047 pro mechanické zkoušky materiálů, pod reg.č. ČIA Praha 109/1996 ŠKODA VÝZKUM s.r.o., Tylova 57, 316 00 Plzeň, 019/7732904

PROTOKOL O ZKOUŠKÁCH

č. : 132
List : 2
Počet listů : 2

ZÁKAZNÍK : KRÁLOVODVORSKÉ ŽELEZÁRNY

PŘEDMĚT ZKOUŠEK : PLECH
Zakázkové číslo : 015 - 53/390
Datum převzetí : 26.1.1998
Datum zkoušení : 4.2.1998

VÝSLEDKY ZKOUŠEK:

Tloušťka plechu 5 mm - podélný směr			Tloušťka plechu 5 mm - příčný směr		
označení	KV (J)	KCV (J/cm^2)	označení	KV (J)	KCV (J/cm^2)
1,5	6,8	75,56	01.05.00	4,2	46,67
1,5	6,5	72,22	01.05.00	4,5	50
1,5	7,7	85,56	01.05.00	4	44,44
2,5	6,7	74,44	02.05.00	3,9	43,33
2,5	6,5	72,22	02.05.00	4,5	50
2,5	7,3	81,11	02.05.00	4,5	50
3,5	7,1	78,89	03.05.00	4,1	45,56
3,5	7,6	84,44	03.05.00	3,6	40
3,5	7,1	78,89	03.05.00	3,5	38,89
4,5	7,5	83,33	04.05.00	4,5	50
4,5	4,6	51,11	04.05.00	4,2	46,67
4,5	5,4	60	04.05.00	5	55,56
5,5	4,1	45,56	05.05.00	3,4	37,78
5,5	4,1	45,56	05.05.00	3,8	42,22
5,5	4,8	53,33	05.05.00	4,3	47,78
Průměr	6,25	69,48	Průměr	4,13	45,93

V Plzni: 4.2.1998

ŠKODA VÝZKUM s.r.o. — AKREDITOVANÁ ZKUŠEBNÍ LABORATOŘ

Ing. Václav Mentl, CSc.
vedoucí laboratoře

Uvedené výsledky zkoušek se týkají jen předmětů těchto zkoušek. Veškeré porovnávání naměřených hodnot s hodnotami požadovanými je mimo rámec akreditace dle ČSN EN 45 001. Bez svolení zkušební laboratoře smí být protokol reprodukován pouze jako celek.

Fig. 6b:
Attestation of impact strength measusements for 5.00 mm steel.

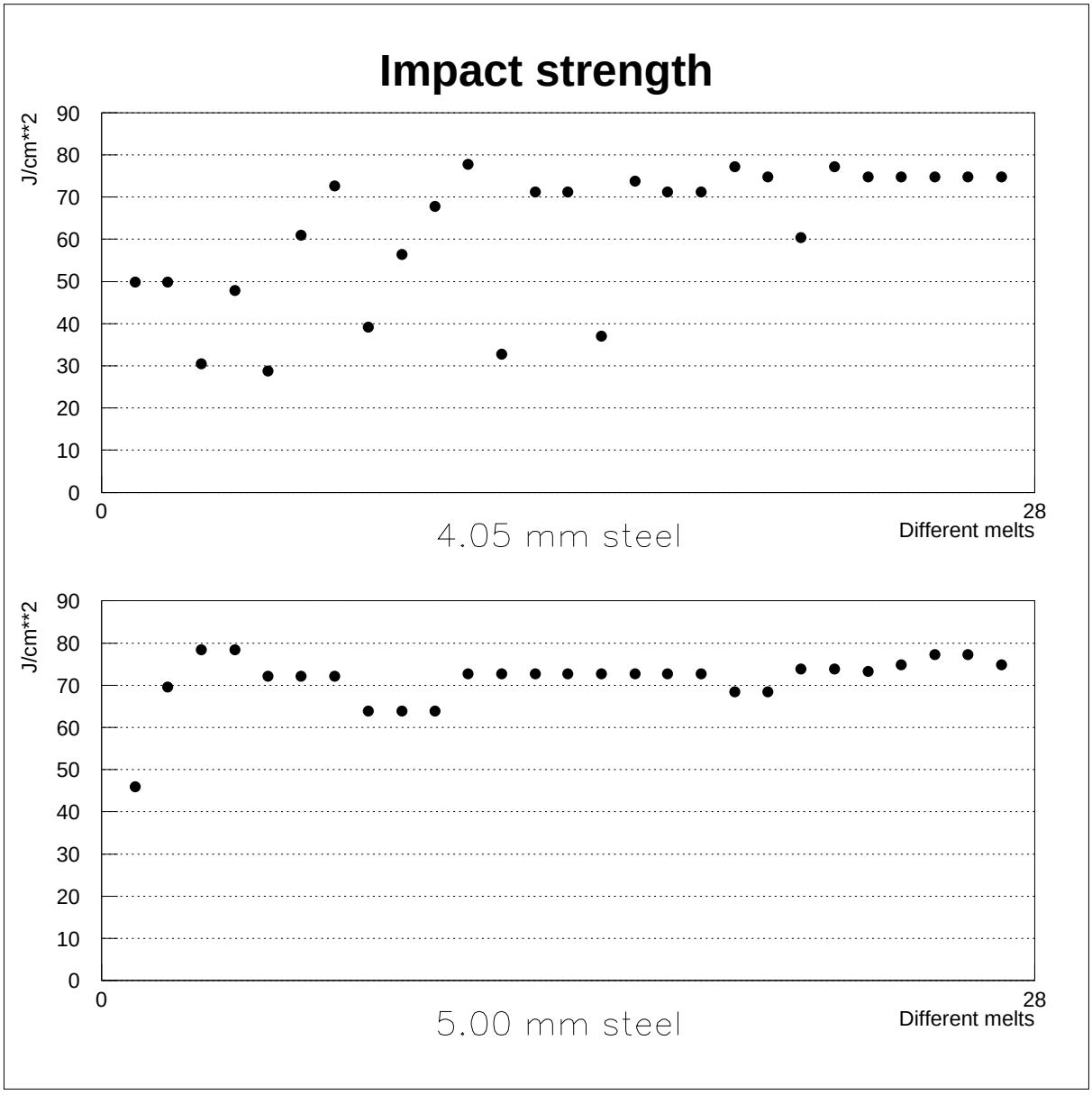


Fig. 6c:
Distribution of impact strength.

CERN IT-2490/PPE/ATL

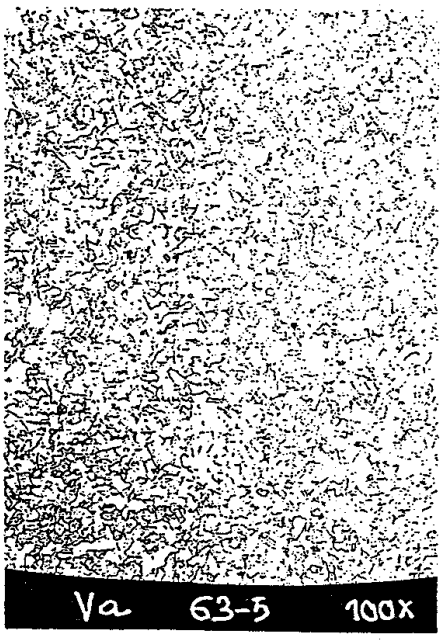
QUALITY CONTROL PLAN
File number: 472
page 1) of 13

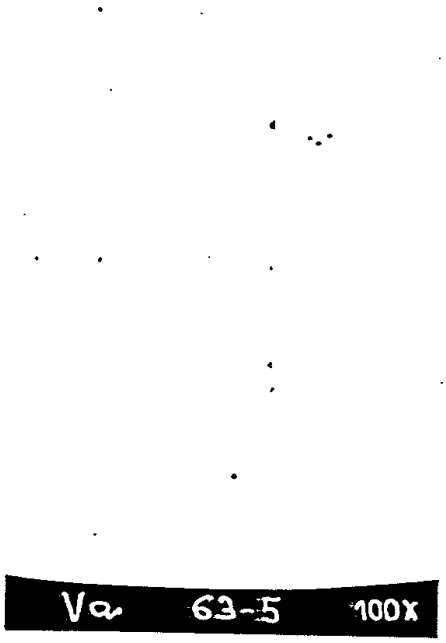
Melt Number:30748	Sheet number:
Coil Number :	Thickness type: 4,05

STRUCTURE AND INCLUSION CONTENT

Grain size (ASTM E 112-83) (μm) ....37,8.....
37,8

Inclusion content (ASTM E 45-84 method A) class .0,5.....
0,5





Signature of producer :
Date 13. 2. 1998

Approved by CERN - ATLAS:
Signature:
S. R. Marx

Fig. 7a:
Example of the structure and inclusion content for 4.05 mm steel.

CERN IT-2490/PPE/ATL

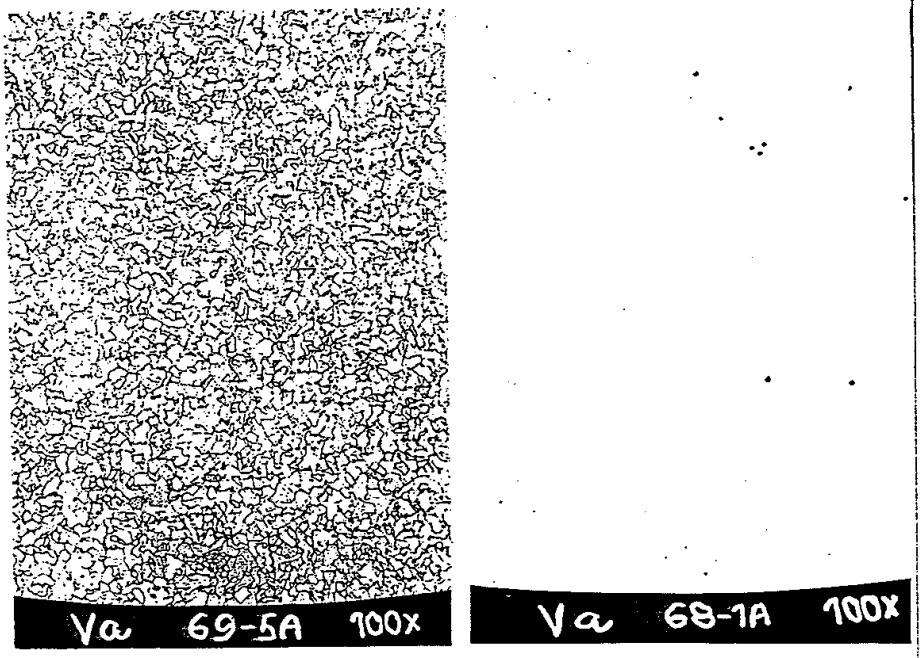
QUALITY CONTROL PLAN
File number: 443
page 9 of 13

Melt Number: 30748	Sheet number:
Coil Number :	Thickness type: 5,00mm

STRUCTURE AND INCLUSION CONTENT

Grain size (ASTM E 112-83) (μm) .....18,9.....
15,9

Inclusion content (ASTM E 45-84 method A) class ..1.....
1



Signature of producer :
Date 13.2.1998

Kraljevorske železarne
VALCOVNA ZA STUDENO d.o.o.

Approved by CERN - ATLAS:
Signature: S.R. Mark

Fig. 7b:
Example of the structure and inclusion content for 5.00 mm steel.

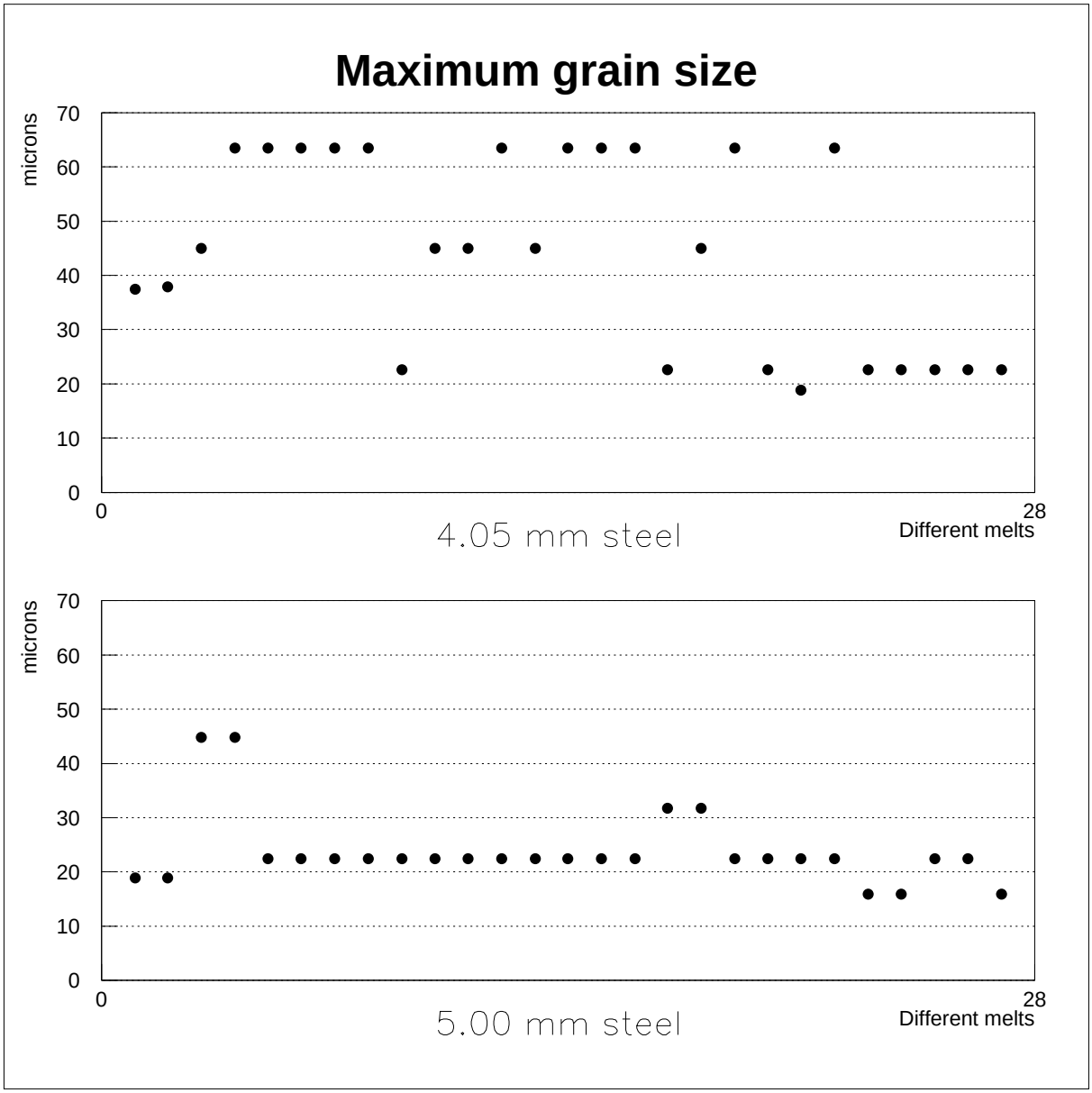


Fig. 7c:
Distribution of maximum grain size.

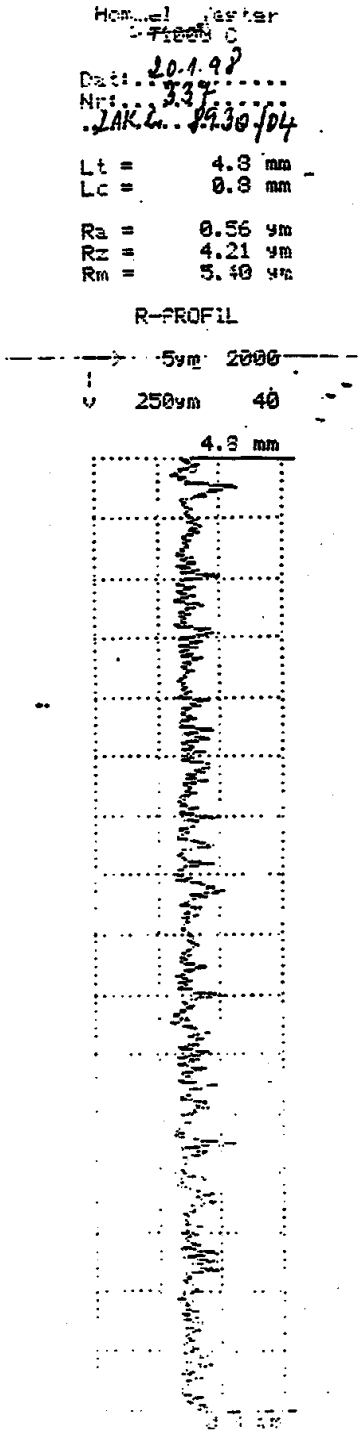


Fig. 8a:
Example of the roughness profile.

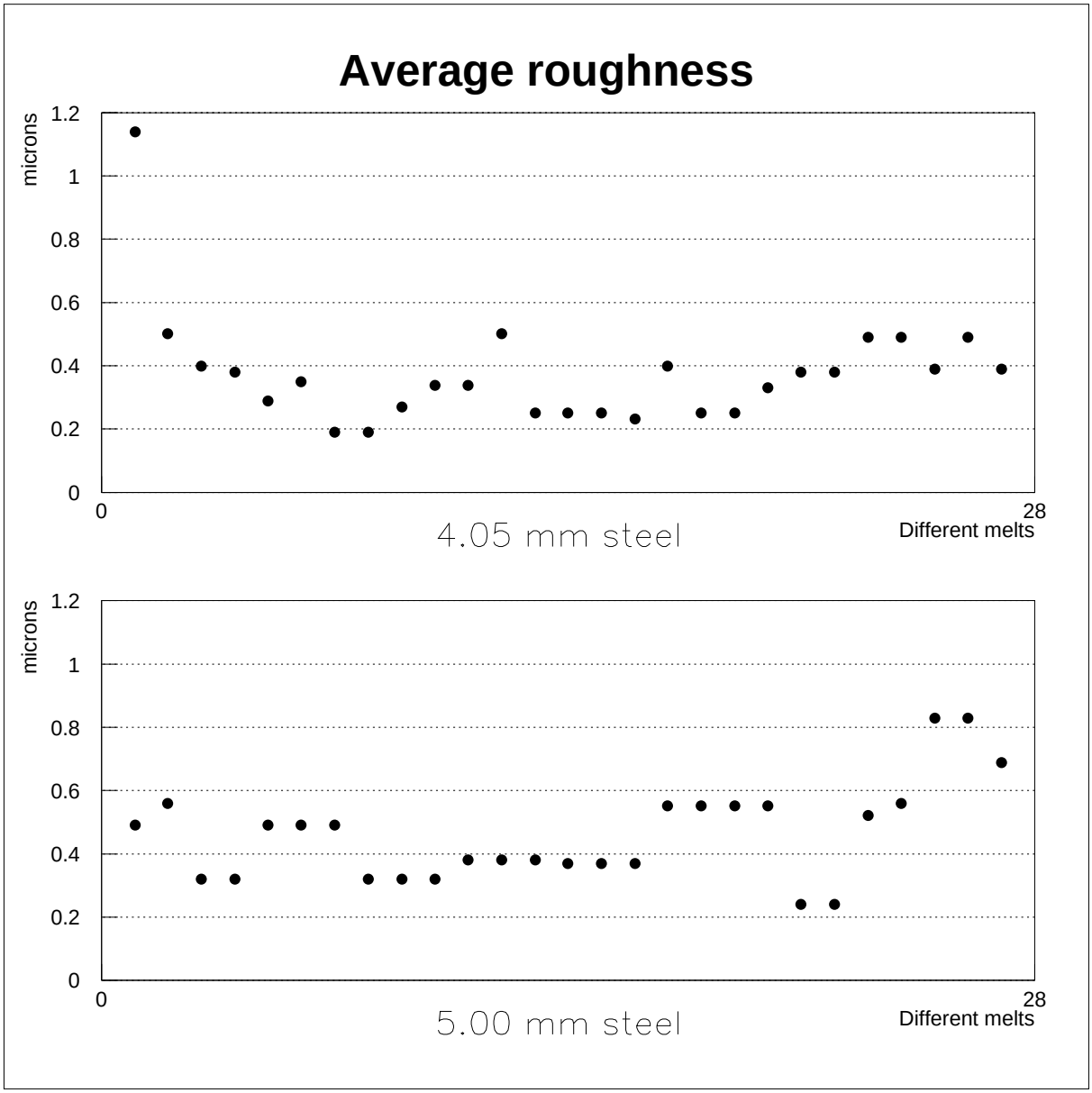


Fig. 8b:
Distribution of average roughness.

I N D U S T R I A L C O E R C I M E T E R (CERN)	
Sample	: T32966
Position	: ?
Measuring Date	: 29.04.1998 08:59:46
Data File	: 29040859.C98
Measuring Direction	: ?
Thickness	: 4.05 mm
Width	: 40.00 cm
Coercivity	: HC = 135.0 (A/m)
Comment	: OK

I N D U S T R I A L C O E R C I M E T E R (CERN)	
Sample	: T34333
Position	: ?
Measuring Date	: 29.04.1998 14:02:36
Data File	: 29041402.C98
Measuring Direction	: ?
Thickness	: 4.05 mm
Width	: 41.00 cm
Coercivity	: HC = 164.1 (A/m)
Comment	: OK

Fig. 9a:
Protocol of magnetic coercivity measurements.

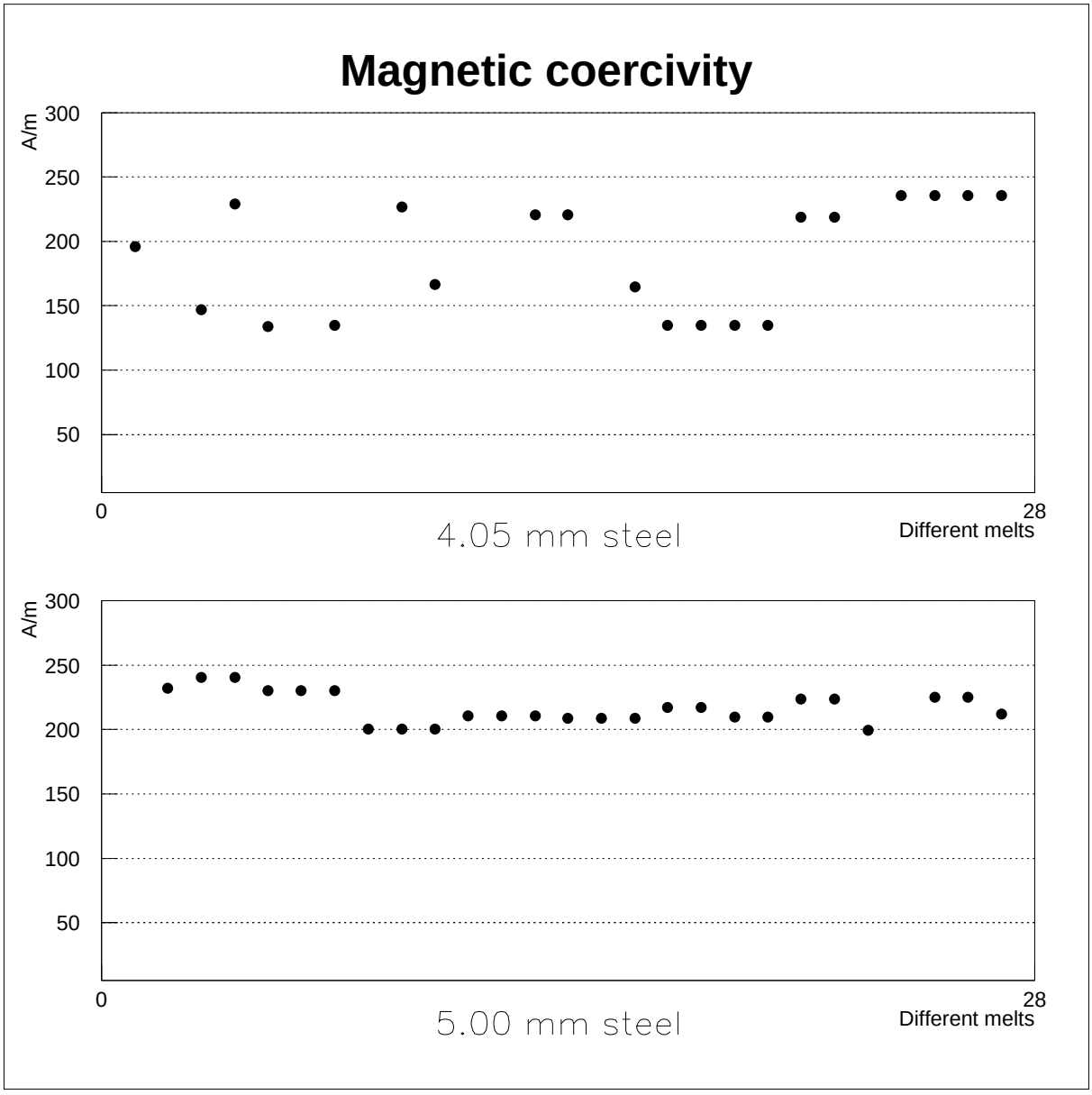


Fig. 9b:
Distribution of magnetic coercivity.

NUMBER OF COIL

P R O T O K O L O S V I T K U 8931/02/01

Vyválcovaném dne : 19.01.98 - Date of rolling

Jakost: 11375 Hmotnost [kg]: 2125 Šířka [mm]: 410

Vstupní tl. [µm]: 4150 Cílová tl. [µm]: 4050 Výstupní tl. [µm]: 4050

Délka [m] : 162 Délka v toler. [%] : 98.36 Tolerance [µm] : -40/40

Step of rolling	Lenght		True thickness				Input tension	
			Výstupní tl. [µm]				Vst. tah [kN]	
	Úběr	Délka	E	δ	Cp	Cpk	E	δ
	1	162	4059.9	10.5	1.27	0.96	0.8	0.6

Step of rolling	Output tension		Speed of rolling		Power of rolling	
	Výst. tah [kN]		Válc. rychl. [m/s]		Válc. síla [kN]	
Úběr	E	δ	E	δ	E	δ
1	46.8	0.8	0.7	0.22	632	31

0.0 5.5 0.0 5.5 32.8 92.9 289.6 322.4 185.8 32.8 16.4 16.4

akost / Grade — Hmotnost / Weight — Sirka / Width

stupni tl./Thickness before rolling — Cilova tl./Final thickness — Vystupni tl./Thickness after rolling

elka / Lenght of coil — Delka v toler./Lenght in tolerance — Tolerance / Thickness tolerance

Fig. 10:
Thickness measurement during the cold rolling.

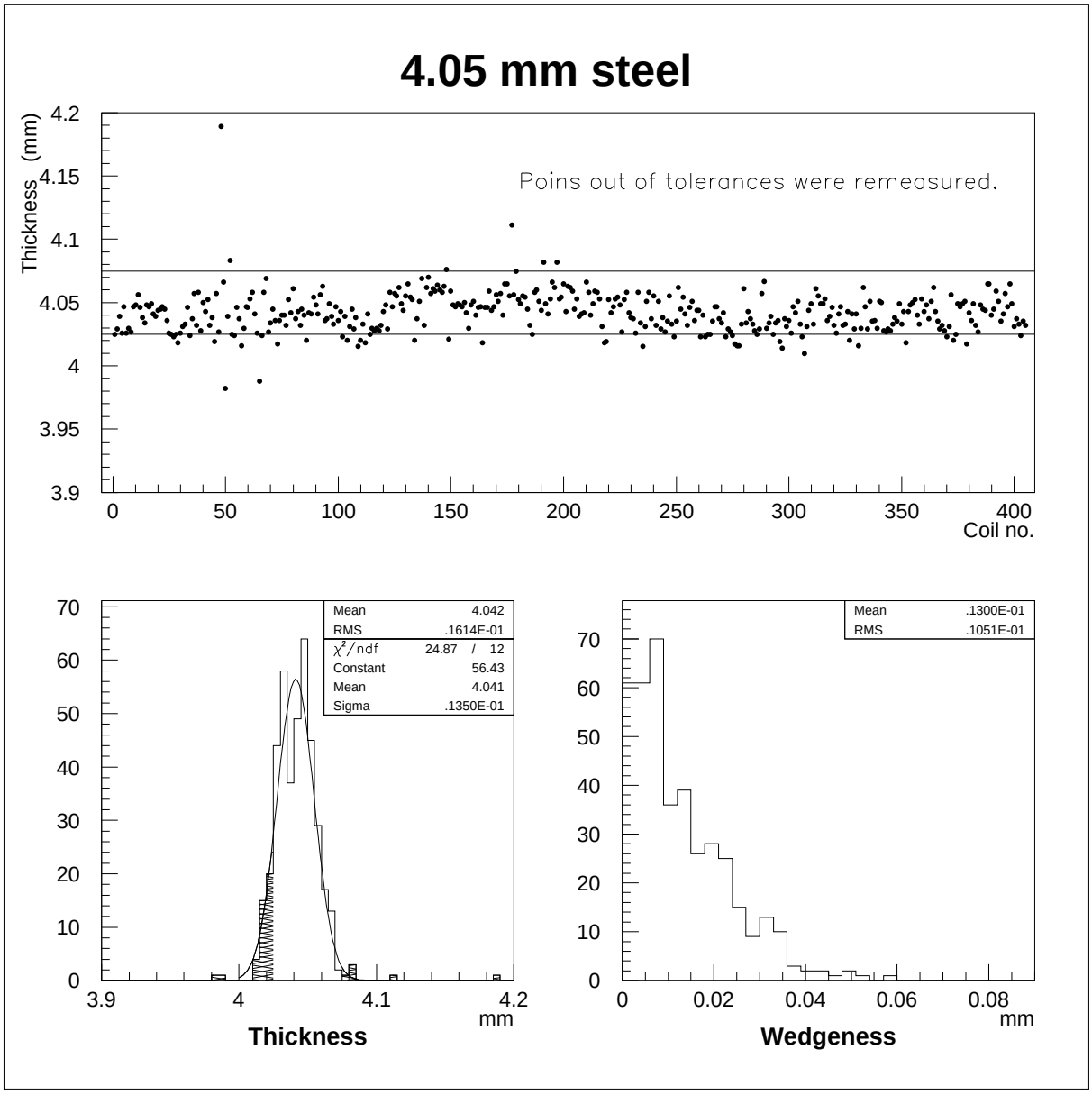


Fig. 11a:
Thickness and wedgeness distributions for 4.05 mm steel.

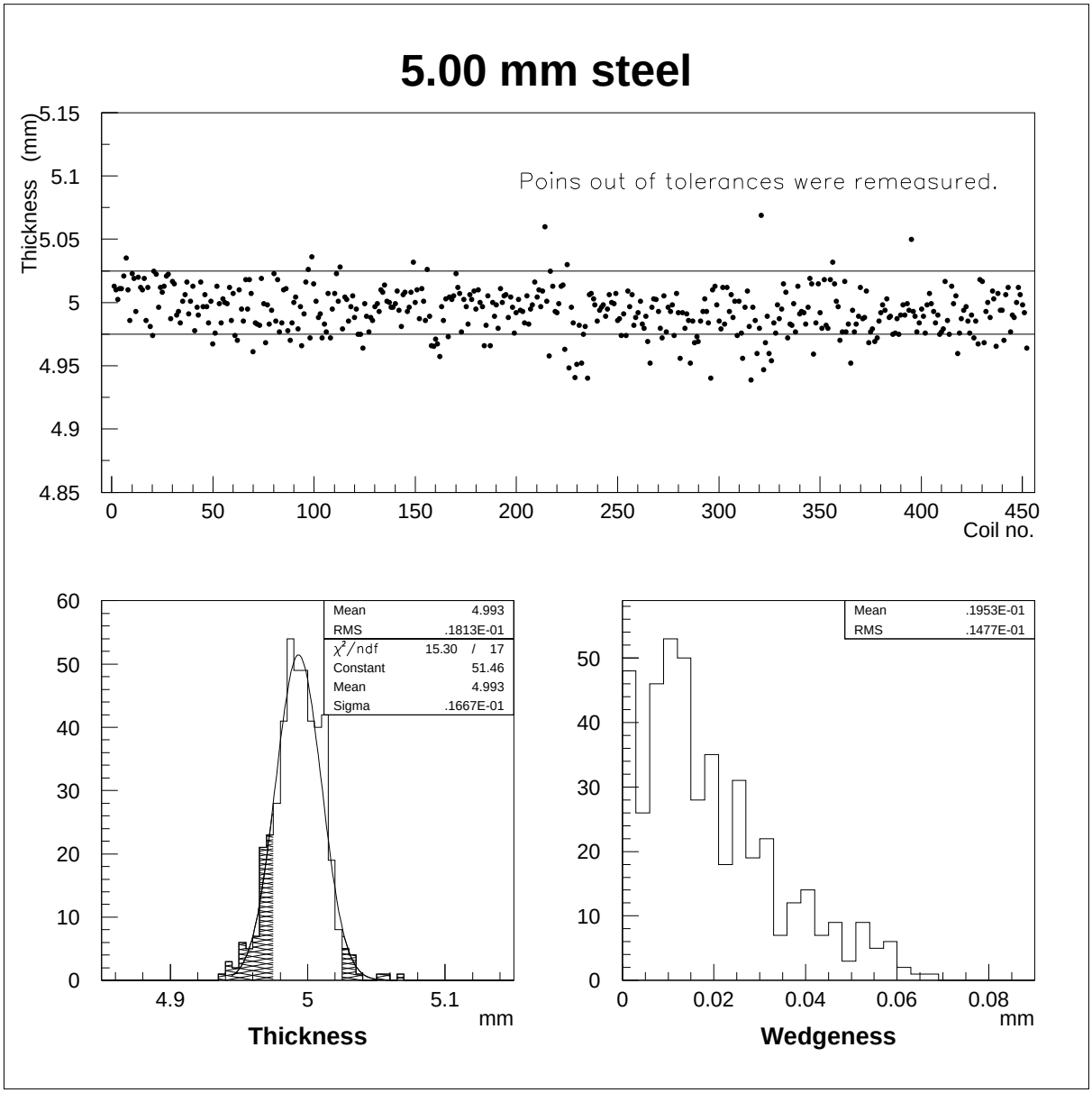


Fig. 11b:
Thickness and wedgeness distributions for 5.00 mm steel.

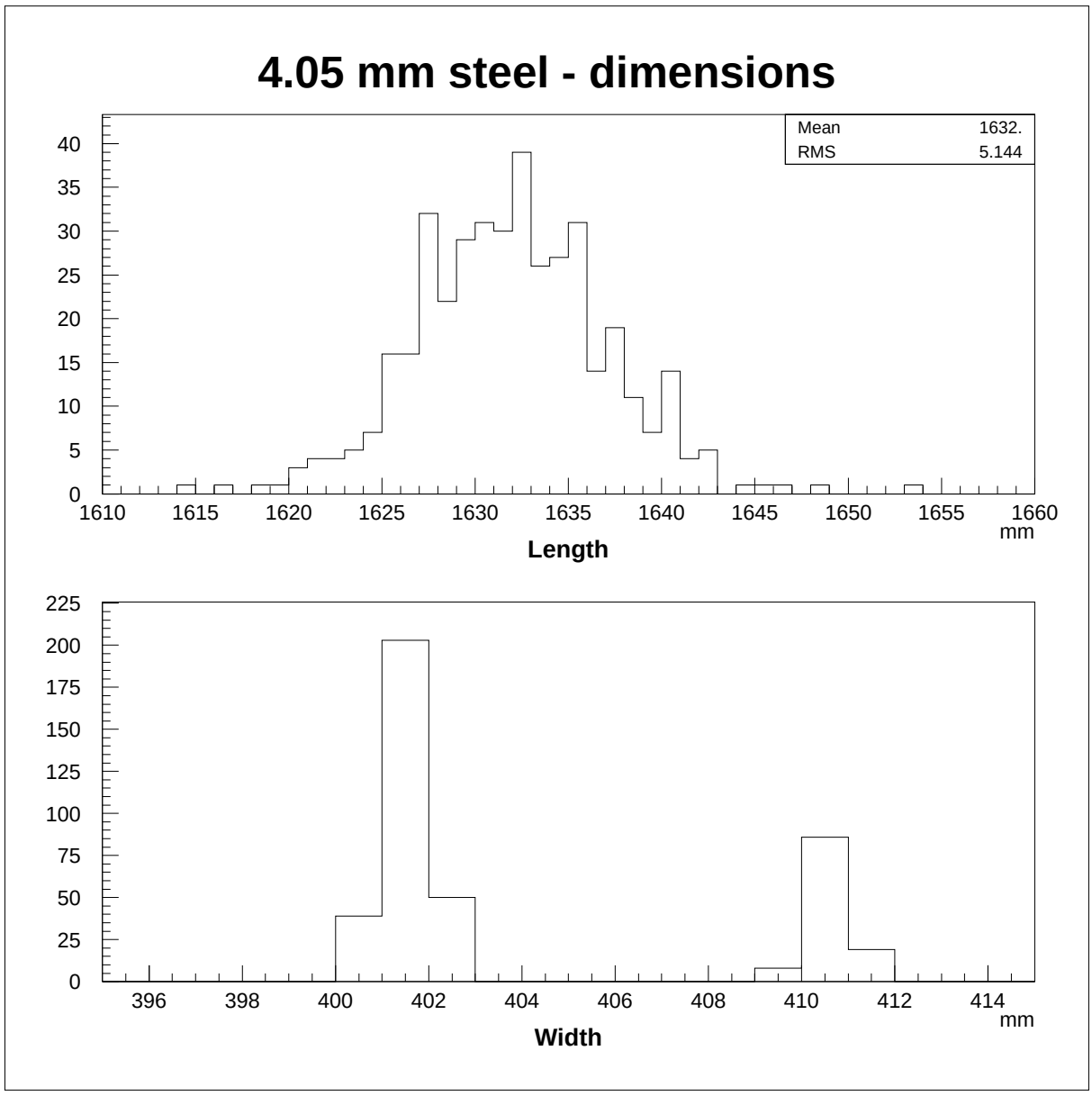


Fig. 12a:
Dimensions for 4.05 mm steel.

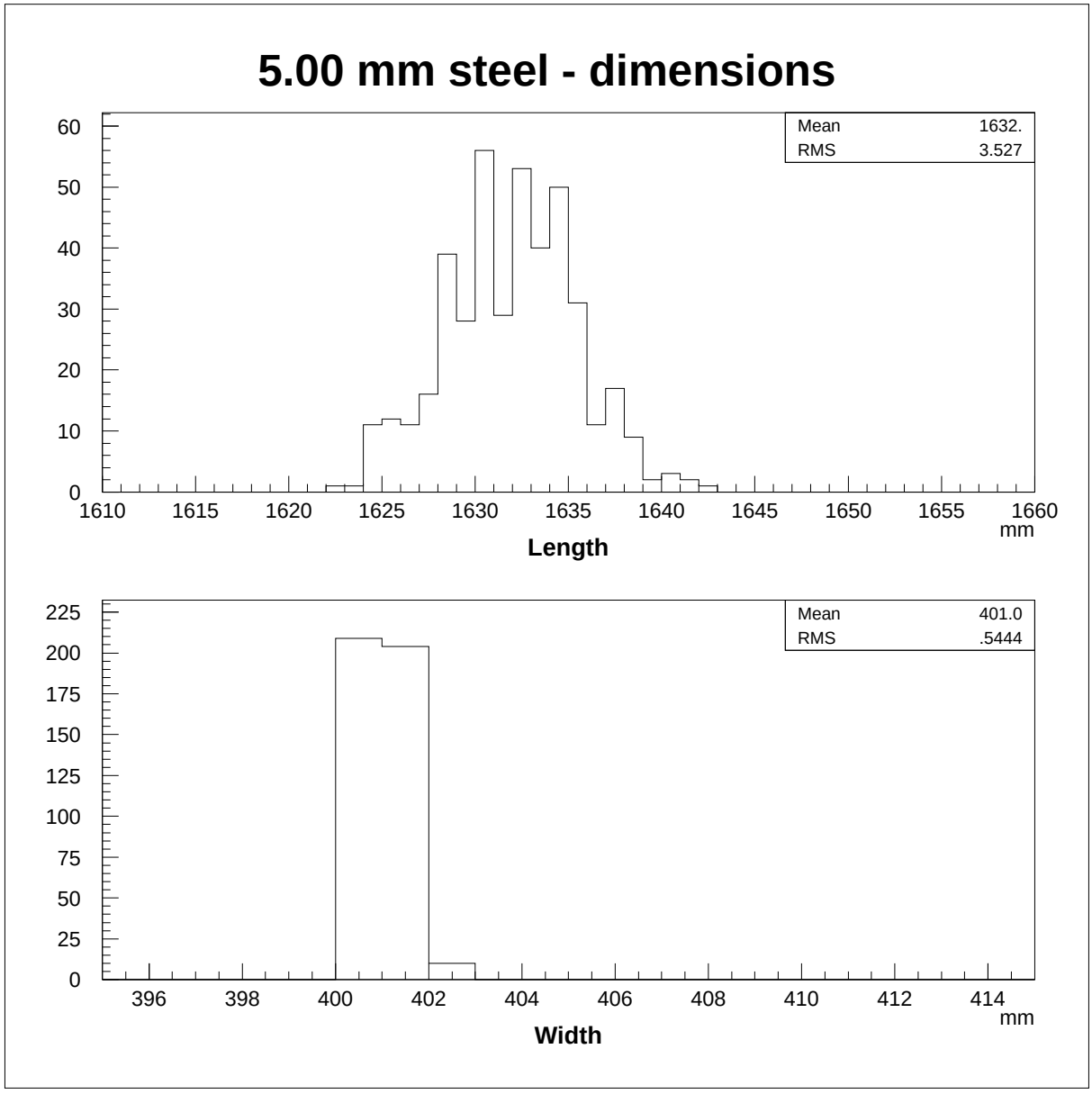


Fig. 12b:
Dimensions for 5.00 mm steel.

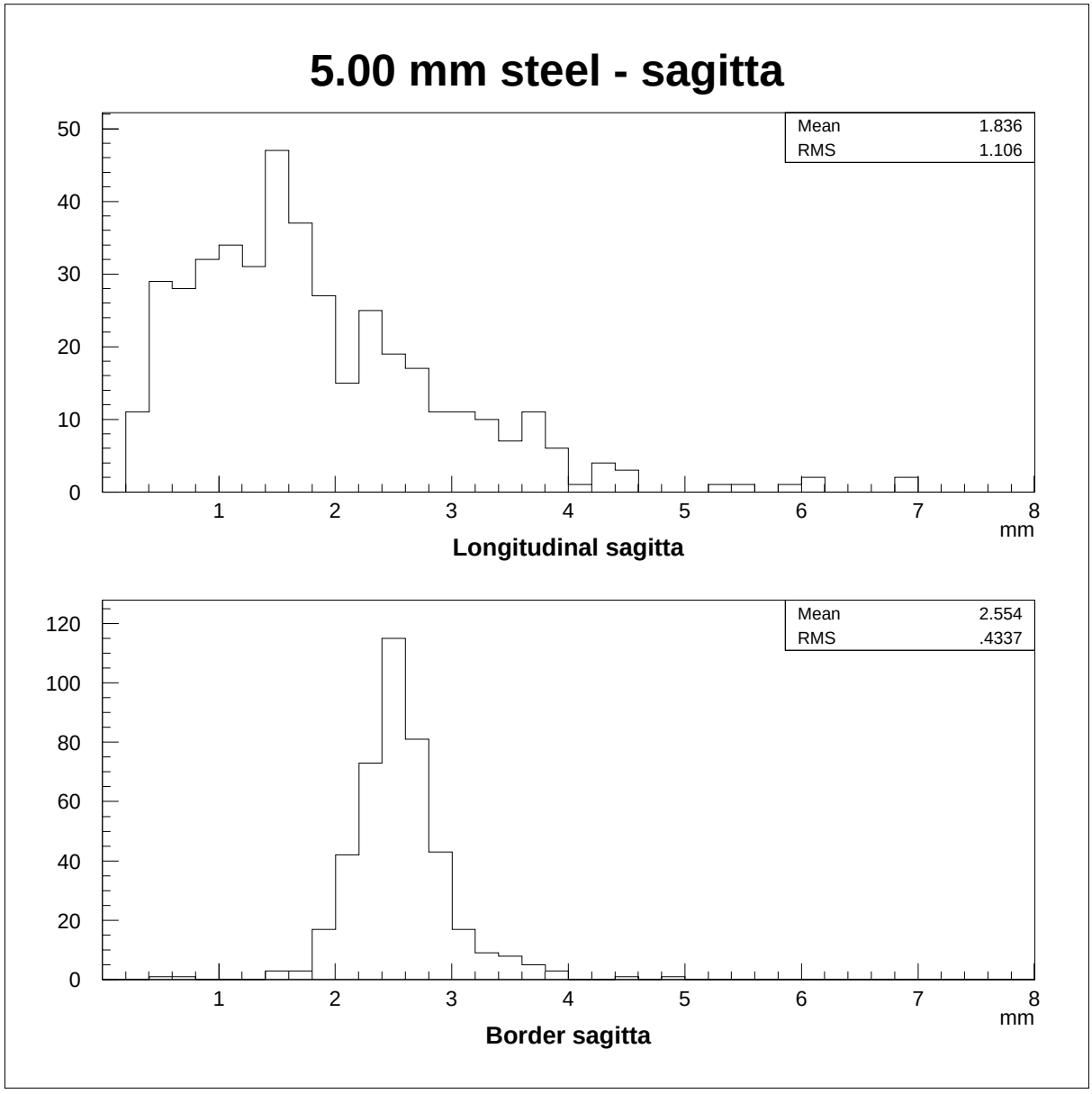


Fig. 13:
Sagitta for 5.00 mm steel.