TILECAL-NO-xxx
xx September 1996

The Procurement of the steel absorber for the TILECAL barrel module 0

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Abstract

In the paper we rewiev the experience with the steel from Cold Rolling Mill Kraluv Dvur near Prague, where the steel for barrel module 0 prototype of the TILECAL calorimeter was fabricated. The measurements of the tolerances, mechanical properties and the chemical composition are presented.

1 Introduction

First contacts with Valcovny Kraluv Dvur near Prague - the possible supplier of the steel for the absorber of the TILECAL calorimeter were established in 1992. During 1992-1994 the Prague group bought and tested several samples of the steel. Produced steel was of very good quality in mechanical properties and dimension tolerances.

- In 1992 we have ordered two sheets of the dimensions 1500x350x4 mm^3 with required thickness tolerances 4.00 $\pm$ 0.05 mm. Measured values of tolerances were 3.99 $\pm$ 0.02 mm.

- In 1994 we have ordered about one ton of sheets with the dimensions 1620x400x4.05 mm^3 and 1620x400x5.00 mm^3. Required precision in the thickness was 4.05 $\pm$ 0.05 mm and 5.00 + 0.00 - 0.10 mm. Measured values of the samples of ten sheets of both thickness were 4.03 + 0.04 - 0.03 mm and 4.93 + 0.04 - 0.03 mm, i.e. again very well within required specifications.

The steel made according to the norm CSN 411343 is full equivalent of prescribed steel defined by the Euronorm EN 10025 [1]. The chemical composition of this steel with respect to the amount of carbon, additive elements (Si, Mn) and harmfull elements (P, S) ensures prescribed mechanical properties (R_m and R_e). Very small amount of nitrogen has not important influence on mechanical properties mainly for structures without cyclic loading. The steel has a good plastic properties which can be classified by elongation A(%).

The structure is mostly ferritic with small amount of pearlite. The ferrit is interstitial solid solution of carbon and substitional solid solution of manganese and silicon in alpha iron. Pearlite is mixture of two phases - ferrite and cementite (Fe_3C). Both phases are ferromagnetic. The Curie point for ferrite is at 760 ^oC and cementite has this point at 230 ^oC. The normal magnetic properties of this steel correspond to magnetic properties of nearly pure iron.

For each coil the plant supplied certificate with chemical composition and mechanical properties of produced steel (see Fig.1,2,3). The amount of most important elements was found to be well within the specification given in[1] (see table 2).

The influence of additive elements on mechanical properties of the steel (Fig.4) is very small. The content of additive elements less than 0.5% changes the hardness and the notch impact strength by less than 10%.

Mechanical properties R_m(ultimate tensile strength) and $R_{p0.2}$(proof stress) as an approximation of R_e(yield stress) of produced steel were measured as well as A_{80}(elongation). The values agreed well with specifications given in[1].

Some characteristics were measured at the Department of Metals of the Faculty of Mathematics and Physics, Charles University [2]:

- The grain size of the steel has been measured for samples of 4 mm and 5 mm thick plates respectively; the measured values in the middle of the plate are $42 \pm 5\mu m$ and $29 \pm 5\mu m$ respectively and near the edge $29 \pm 5\mu m$ and $23 \pm 5\mu m$ respectively.

- The internal stress was measured by measurement of the gap between two pieces of cut plate. The plate was cut by means of milling cutter in order to avoid the additional stress. No gap was found within measurement errors (0.1 mm).

- The microhardness has been measured by Knoop's pyramid (loading 50 g), giving for 4 mm and 5 mm thick steel the values in the middle of the sheet 172 ± 10 and 204 ± 10 respectively and near the edge 194 ± 12 and 200 ± 12 respectively.

- The magnetic coercitive force has been mesured in two perpendicular directions (along and perpendicular to the rolling direction) in the middle and near the edge of 4 mm and 5 mm plates. The measured values are given in table 1:

Steel thickness	Coercitive force H_c [Oe]			
	middle		near edge	
	parallel	perpendicular	parallel	perpendicular
4 mm	2.91 ± 0.3	4.23	1.32	4.62
5 mm	3.96 ± 0.3	4.49	1.98	4.75

Table 1. The values of the coercitive force H_c in Oersted measured for sheets of 4 mm and 5 mm steel for two orientations (parallel and perpendicular) and different positions of measurement on the plate

Very detailed measurements of magnetic characteristics were done by Dubna group[3]. Isotropy of the magnetic properties is more important for 5 mm steel as the majority of the magnetic return flux goes through master plates. The anisotropy of the coercitive force for 5 mm plates is less than measurement error. For 4 mm plates the anisotropy of few percent was measured. This has no significant influence because of dimensions and distribution of the spacers inside TILECAL.

During TILECAL meeting in June 1995 at CERN, it was decided to order the steel needed for the construction of barrel Module 0 at the Cold Rolling Mill Kraluv Dvur.

2 The order

For the construction of full scale barrel module 0 of the TILECAL calorimeter, the order for following amount of the steel was placed:

- 600 sheets of the dimensions 1620 x 400 x 4.10 mm^3 in sheets with thickness tolerance $\pm 40 \mu m$.
- 1200 sheets of the dimensions 1620 x 400 x 4.95 mm^3 in the coils with thickness tolerance $\pm 45 \mu m$.
- global tolerances: the average longitudinal profile over the entire coil length is kept within $\pm 0.020 mm$ from the nominal value (4.10 mm and 4.95 mm).
- the surface quality must be free of visible defects and the roghness must be of N10 quality ($R_a = 12.5$ μ m).

Further specifications as well as quality control procedure are described in[1].

The material was suplied by the plant in the end of September 1995. The total amount was

7 coils of 4.10 mm thick steel cut into sheets

17 coils of 4.95 mm thick steel

This steel is marked as 95 in the tables and figures.

To complete the necessary amount of 4mm plates for the Extended Barrel, another order (with the same tolerances) was placed in the plant. One coil (2380 kg) of 4 mm (4.1 mm) steel was produced and cut into 99 sheets of the dimension 1620x430x4.1 mm^3. This steel is marked as 96 in tables and figures.

3 Technological procedure from steelmaking to cold rolled sheets

The whole procedure of the steel fabrication is as follows:

- Procedures done in NH Ostrava - the producer of hot rolled sheets
  - melting of charge in open-hearth furnace, purification and reduction of amount of carbon and other elements to obtain prescribed chemical composition
  - deoxidation
  - casting of ingots
  - hot rolling of ingots by different procedures to sheets with thickness 5.3 mm
- Procedures done in Cold Rolling Mills, Kraluv Dvur:
  - acid cleaning (HCl)
  - cold rolling of sheets: $5.3mm \rightarrow 4.95mm$ and $5.3mm \rightarrow 4.15mm$. Sheets with thickness 4.15 mm were anealed just after cold rolling in continuous furnace with protective atmosphere to remove deformed structure by recrystallisation and to remove internall stresses.
  - cold rolling $4.15mm \rightarrow 4.10mm$.
  - cutting of strips to prescribed width and cutting of 4.10 mm thick strips into plates.

To receive structure with the same quality (mainly with the same grain size), it is necessary to keep the same procedure as was described above.

The wedge profile of the steel strips resulted from the production of the hot rolled strips in NH Ostrava. During the cold rolling process this effect can not be completely compensated.

4 Sheets production and packing

The coils 5 mm thick and the plates 4 mm thick have been transported from the Cold Rolling Mill in Kraluv Dvur to the factory TRANSPORTA in Chrudim. Here the coils have been cut using the power shears. The plates (4 and 5 mm thick) have been then levelled on a straightening press.

The 5 mm thick plates have been packed in 8 wooden cases, each containing about 4.3 tons of the steel. The plates have been oiled and wrapped in water proof paper STAKOR. The packing was suitable for the oversea transport. The cases were shipped to ANL.

The 4 mm thick plates have been packed on 16 pallettes (14 loaded with 40 plates and 2 with 20 plates). The total weight was 12.1 tons. The plates have been oiled and wrapped in water proof paper STAKOR. The pallettes were send to Barcelona and Dubna by truck.

5 Sheets planarity

The planarity of the steel sheets was tested by measuring the sagitta, describing the curvature of the sheet. The sagitta measured in the direction of the rolling was measured on the base 1m long. The sheet was laid on an even plane (thick steel plate) and then was the sagitta measured by a steel ruler. The values for 4 mm thick sheets was compatible with 0 (no measurable sagitta), for 5 mm thick sheets the measurements give sagitta between 0 and 3 mm.

In the process of cutting the strip to sheets, the shears deform the edge of the sheet. The sagitta (in the direction perpendicular to the rolling) for 4 mm thick sheets was between 1 and 4 mm on 400 mm base and for 5 mm thick sheets between 0 and 4 mm on 400 mm base. This sagitta was removed by straightenning the sheets after cutting.

Some master plates (5 mm sheets) have shown a "wavy shape". This was probably caused by adjusting the press at the beginning of the straightenning procedure.

6 Mechanical properties and the chemical composition

Mechanical properties of the steel were measured for the samples of each coil and were delivered together with chemical composition certificates (see Fig.A.1-5). Values of R_m are about 350 MPa for 4 mm steel (95), about 323 MPa for 4mm steel (96) and about 440 MPa for 5 mm steel. Lower value of R_m for 4 mm steel was achieved by the annealing (10 hours at 730^{o}C). For 5 mm steel the annealing will be also possible to reach specified value of R_m.

The chemical composition of the steel is well within specification for carbon and harmful elements (phosphorus and sulphur). The content of additive elements (Si, Mn) has less than 10% influence on mechanical properties.

7 Thickness tolerances

For each coil the histogram of thickness measured along one line approximately in 1/3 of the width was supplied (see Appendix A).

The samples of 1m length were cut of each coil for quality check done by ATLAS representative directly in the plant. The samples were measured according to specification given in [1] in 12 points along the edges. The results of this measurements for 4 mm and 5 mm materials are given in Table 3. and Table 4. and plotted on Fig.5 and Fig.6 respectively. Plots of deviations of measured mean values and maximal found deviations from the nominal values are on Fig.7 and Fig.8 for 4mm and 5mm steel respectively.

Mean values are plotted by full circles. The steel strips were of wedge profile, the thickness of thicker and thinner sides are represented by diamonds. All measured values for 4mm steel are within specified tolerances. Taking into account the precision of measurements (error bars on Fig.5 and Fig.6) we can conclude that the measured values of 14 samples of 5 mm steel are within specified tolerances. One sample was not measured and another two were found thicker than required maximal thickness 4.995 mm.

The mean values of the strips thickness measured on-line during the rolling are within specified global tolerances $\pm 20\mu$ m for all 7 coils of 4 mm thick steel. The mean values of the thickness of 4 out of 17 coils of 5 mm steel are outside the global tolerances (4.920 mm, 4.920 mm, 4.927 mm and 4.923 mm are lower than 4.950-0.020=4.930 mm).

8 Conclusions

- the thickness tolerances of 13 tons (95) as well as 2.4 tons (96) of 4 mm steel plates were measured to be within TILECAL specifications.
- the thickness tolerances of 32 tons of 5 mm steel plates were measured to be within TILECAL specifications for 15 out of 17 coils.
- the global tolerances for 4 mm coils are within the TILECAL specifications; for 5 mm coils are 4 out of 17 coils outside the TILECAL specifications.
- the spread of thickness is mainly caused by the wedge profile of hot rolled steel produced in NH Ostrava.
- the surface quality corresponds to the order.

- the content of carbon is less than 0.1%, the percentage of harmful elements is less than prescribed by the norm. The influence of additive elements on mechanical properties is less than 10%.

- mechanical characteristics (R_m) of annealed 4 mm steel met TILECAL requirements. The relative change of the thickness during the cold rolling process is very small for 5 mm material. Therefore it was not annealed and the values of R_m for the 5 mm material are about 30% higher. Annealing of the 5 mm material will reduce R_m to specified value.

- The quality of the steel produced by Cold Rolling Mill Kraluv Dvur corresponds to TILECAL requirements. Better homogenity in tolerances, mechanical characteristics and chemical composition can be achieved if the raw material is carefully selected well before the production.

- The steel was successfully used for the construction of Module 0.

Specification	Chemical composition (max. value)						Mechanical properties	
	C [%]	P [%]	S [%]	N [%]	Mn [%]	Si [%]	R_e/R_p [MPa]	R_m [MPa]
CERN[1]	0.20	0.05	0.05	0.009			235	340
Euronorm EN10025	0.17	0.045	0.045	0.009	1.40			
CZ norm CSN 411343	0.16	0.045	0.045	0.007				
Module 0:								
5 mm (95)	0.08	0.014	0.016		0.416	0.205	283÷435	433÷461
4 mm (95)	0.07	0.016	0.022		0.46	0.223	230÷347	344÷353
4 mm (96)	0.10	0.013	0.024		0.362	0.058	205÷209	321÷325

Table 2. Specifications for low carbon steel given by the TILECAL collaboration (CERN [1]), by the Euronorm EN10025 and the Czech norm CSN 411343 together with the values measured of the steel supplied for the Module 0.

References

[1] Atlas, Tilecal collaboration, ATLAS Internal Note TILECAL-NO-51 (1995) Addendum to the TILECAL-NO-51, CERN, 19 June 1995.

[2] V. Sima, TILECAL-TR-40, 27 June 1995.

[3] V.V. Kalinichenko, S.B. Fedorenko, ATLAS Internal Note TILECAL-NO-59(1995)

Královdvorské železárny
národní podnik
Beroun 7 – Králův Dvůr

Válcovna za studena
s.r.o.
Králův Dvůr

List č. ____

Jednotky SI pevnost uváděna v N/mm²

HUTNÍ OSVĚDČENÍ ČÍS. 748

Objednavatel NC UK Mat. fyz. fakulta Praha

Zboží pásová ocel válcovaná za studena

Číslo zakázky 1177 Číslo objednávky

Číslo návěští

Jakost	Rozměr	Množství	Tavba	Mechanické hodnoty: pevnost N/mm²	Mechanické hodnoty: tažnost	Mechanické hodnoty: prohloubení
11343.01	510 x 5 mm	210 kg	79062			
			$R_{p\,0,2}$	R_m	A_{80}	
			274 MPa	368 MPa	33,1 %	
			281	376	27,9	
			276	370	30,7	

Chemické složení:

C 0,11 % Si 0,07 % Mn 0,38 % P 0,008 % S 0,014 %

Berouně dne 27.3.1995

KŽ-59-87-130

TZ 66-18724-80-0

Figure 1:
The example of the metallurgical certificate.

Method: C-OCEL Date: 23. 3.1995 Time: 12:58 % **Average**
VZOREK ; VA1 TECHNOLOG : ; 11343 : ; POT.KAH. 1803 :

FE	C	SI	MN	P	S	NI	CR	CU	AL	MO	V	SB	SN
99.23	0.117	0.070	0.384	0.008	0.014	<0.025	0.020	0.094	<0.005	<0.005	0.002	<0.000	0.029

AS	TI	W
<0.002	0.005	<0.000

Method: C-OCEL Date: 23. 3.1995 Time: 12:59 % **Average**
VZOREK ; VA1 TECHNOLOG-2 : ; 11343 : ; POT.KAH. 1803 :

FE	C	SI	MN	P	S	NI	CR	CU	AL	MO	V	SB	SN
99.24	0.111	0.073	0.388	0.007	0.014	<0.025	0.015	0.091	<0.005	<0.005	0.000	<0.000	0.017

AS	TI	W
<0.002	0.023	<0.000

Method: C-OCEL Date: 23. 3.1995 Time: 13:00 % **Average**
VZOREK ; VA1 TECHNOLOG-3 : ; 11343 : ; POT.KAH. 1803 :

FE	C	SI	MN	P	S	NI	CR	CU	AL	MO	V	SB	SN
99.26	0.120	0.066	0.374	0.008	0.014	<0.025	0.019	0.092	<0.005	<0.005	0.001	<0.000	0.025

AS	TI	W
<0.002	0.005	<0.000

Figure 2:
Chemical composition of the steel.

	$\langle t\rangle_{online}$	$\langle t\rangle_{offline}$	Δt	t_{max}	Δt_{max}	t_{min}	Δt_{min}
(95)	4.119	4.092	-0.008	4.116	+0.016	4.066	-0.034
		4.075	-0.025	4.090	-0.010	4.060	-0.040
	4.117	4.109	+0.009	4.126	+0.026	4.094	-0.006
	4.127	4.101	+0.001	4.126	+0.026	4.070	-0.030
	4.116	4.098	-0.002	4.116	+0.016	4.070	-0.030
	4.117	4.106	+0.006	4.128	+0.028	4.078	-0.022
	4.117	4.088	-0.012	4.106	+0.006	4.064	-0.036
(96)	4.097	4.101	+0.001	4.116	+0.016	4.087	-0.013

Table 3. The thickness measured in 1/3 of the width of the coil during the production ($\langle t\rangle_{online}$), mean value of thickness obtained from the quality checking ($\langle t\rangle_{offline}$) and its deviation ($\Delta t$) from nominal value 4.10 mm. The maximal and minimal thickness (t_{max} and t_{min}) and their deviations (Δt_{max} and Δt_{min}) from the nominal value 4.10 mm. The error of measured mean value is estimated to be 0.003 mm, the errors of t_{max} and t_{min} are about 0.010 mm.

Číslo vzorku: Va/2
Zákazník: PRAHA Fakulta

Rychlost zatěžování:
v1 = 6.4 mm/min
Původní rozměry: Lo = 80.00 mm
5.00 x 20.00 So = 100.00 mm²
Konečné rozměry: L = 102.30 mm

23-3-1995 11:14

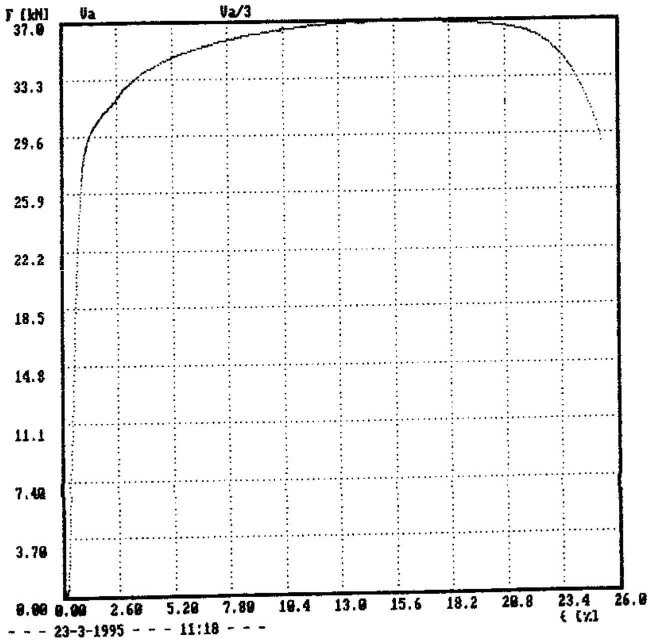
Naměřené parametry:
Rp(0.20) = 281 F[kN] = 28.1
Rm[N/mm²]= 376 F[kN] = 37.6
A[%] = 27.9

Číslo vzorku: Va/3
Zákazník: PRAHA Fakulta

Rychlost zatěžování:
v1 = 5.9 mm/min
Původní rozměry: Lo = 80.00 mm
5.00 x 20.00 So = 100.00 mm²
Konečné rozměry: L = 104.60 mm

23-3-1995 11:18

Naměřené parametry:
Rp(0.20) = 276 F[kN] = 27.6
Rm[N/mm²]= 370 F[kN] = 37.0
A[%] = 30.7



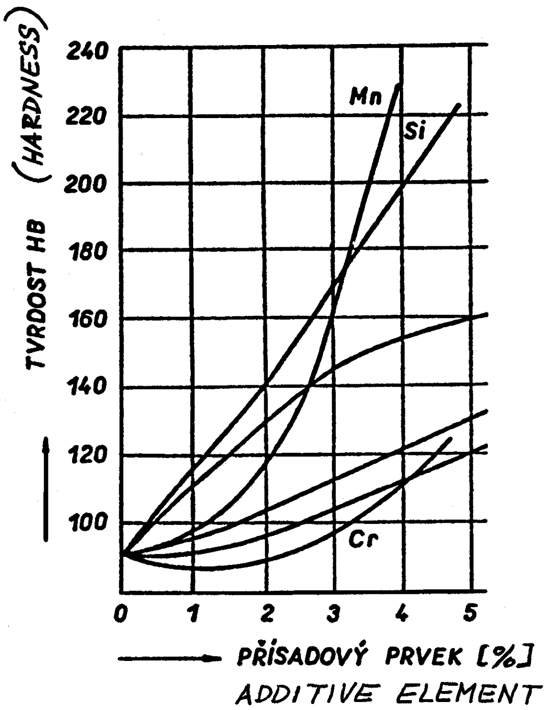
Specimen No: Va/3
Customer: PRAHA Fakulta

Loading speed:
v1 = 5.9 mm/min
Orig. dimensions: Lo = 80.00 mm
5.00 x 20.00 So = 100.00 mm²
Final dimensions: L = 104.60 mm

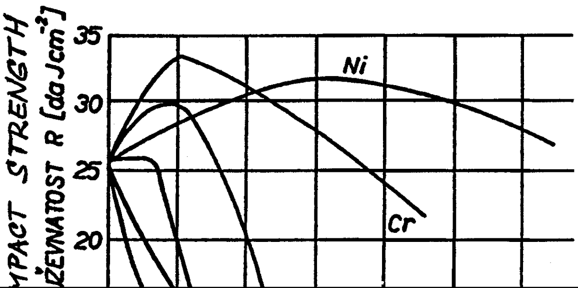
23-3-1995 11:18

Measured values:
Rp(0.20) = 276 F[kN] = 27.6
Rm[N/mm²]= 370 F[kN] = 37.0
A[%] = 30.7

Figure 3:
Measured values of R_m(ultimate tensile strength), $R_{p0.2}$(proof stress) and A_{80}(elongation). The curve shows the dependence of relative elongation ϵ on applied force F.



TVRDOST HB (HARDNESS)
240
220
200
180
160
140
120
100
Mn
Si
Cr
0
1
2
3
4
5
PŘISADOVÝ PRVEK [%]
ADDITIVE ELEMENT



MPACT STRENGTH
ŽEVNATOST R [daJcm-2]
35
30
25
20
Ni
Cr

[redacted]