and guaranteeing Y/T values in compliance with the European market requirements.
The approach used to achieve this goal and the results obtained after the first year of operation are the subject of this article.

METALLURGICAL DESIGN APPROACH

The typical CSM approach to the metallurgical design of structural steels, schematically described in the Fig.1, was used, and followed in its general lines.
In summary, this approach consists of four successive steps:

- Definition of the target properties on strip from the specified properties on pipe and knowledge of the effect that the pipe forming processes has on the properties;
- Definition of target microstructure from the target properties identified in the previous step and knowledge of the relationship between microstructure and steel properties;
- Definition (or verification) of the rolling and cooling operating practices to be applied to the steel to obtain the microstructure and properties identified in the previous steps;
- Verification by industrial testing of the accuracy of the settings and definition of possible corrective actions.

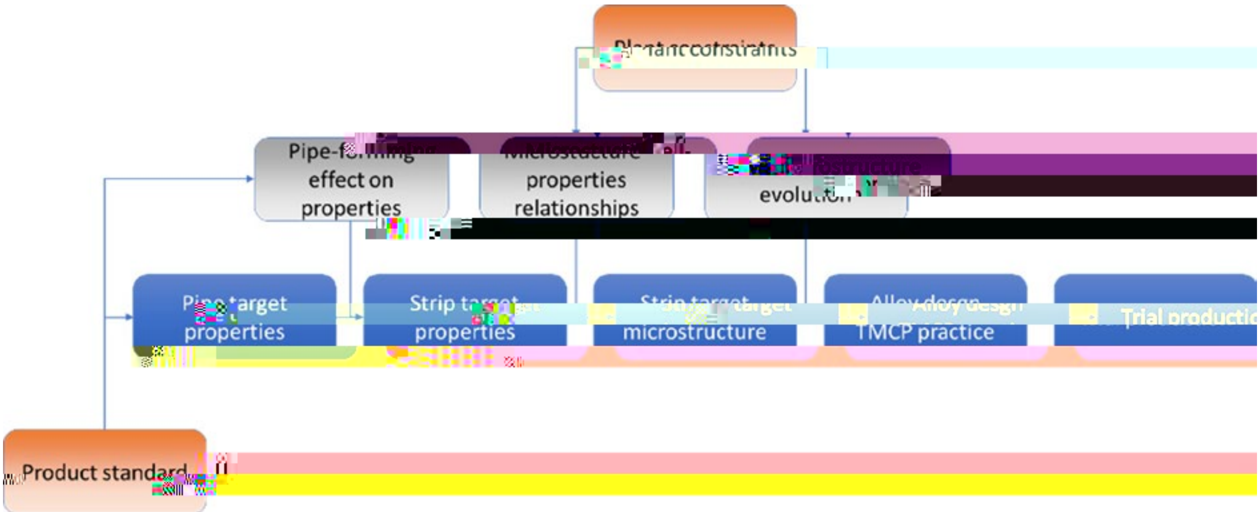

Fig.1 - Typical CSM approach to the metallurgical design of structural steels.

Definition of the strip target properties

The target properties of the pipe, taken from the standard, are summarised in the Tab.1 and Fig.2.
Fig.2 also shows the restriction of the target property window of the strip necessary to account for the loss of mechanical properties when forming the pipe and to compensate the variability due to rolling.

Tab.1 - Target properties of pipe and strip.

TARGET PROPERTIES			
Property	**Unit**	**Pipe**	**Strip**
Y	MPa	415 ÷ 565	495 ÷ 545
T	MPa	520 ÷ 760	590 ÷ 730
Y/T	-	≤ 0.85	≤ 0.80

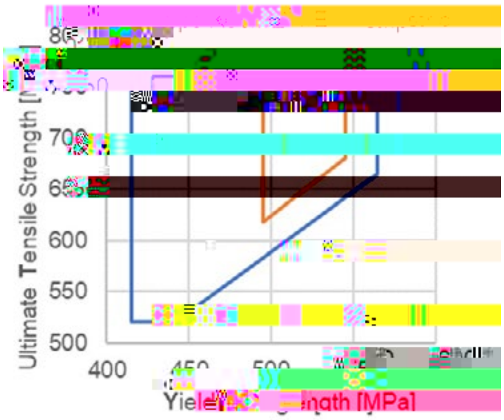

Fig.2 - Target properties windows of pipe and strip.

T[redacted] ffect [redacted]
p[redacted] perties [redacted]
consists in [redacted]
yield streng[redacted]
ultimate te[redacted]
values rem[redacted]
impact tou[redacted]
a dispersio[redacted]
ratio were [redacted]
data into ac[redacted]
summarise[redacted]
Subsequen[redacted]

$$Y_{FP} = Y_0 + \frac{k_Y}{\sqrt{d}} \quad ; \quad T_{FP} = T_0 + \frac{k_T}{\sqrt{d}}$$

where Y a[redacted]
tensile str[redacted]
size chara[redacted]
coefficient[redacted]
equations [redacted]
known ter[redacted]

$$Y_{FP} = 62.6 + 26.1[Mn] + 60.2[Si] + 759[P] + 80[Cu] + 60[Cr] + 45[Ni] + 11[Mo] + 19.7\sqrt{\frac{1000}{d}} + 2000[Nb] + 1000[V]$$

[illegible]

Based on [redacted]
≤ 0.1 and [redacted]
and grain [redacted]
required v[redacted]
ferrite-pea[redacted]

$$Y = Y_{FP}\frac{(PF\%)}{100} + a\frac{(B\%)}{100} + b\frac{(MA\%)}{100}$$

$$T = T_{FP}\frac{(PF\%)}{100} + c\frac{(B\%)}{100} + d\frac{(MA\%)}{100}$$

$$\frac{Y}{T} = \frac{Y_{FP}}{T_{FP}}\frac{(PF\%)}{100} + e\frac{(B\%)}{100} + f\frac{(MA\%)}{100}$$

where (PF[redacted]
polygonal [redacted]
while the c[redacted]

Fig.3 (a) shows the results obtained by applying equations (4) – (6) to the steel grade LC1, used in the past to produce ERW X65ME pipes; in particular, the optimal micro-

[redacted]

Industrial [redacted]

To reduce [redacted]
steel grade [redacted]
the hot mi [redacted]
taken at 5.5 [redacted]
properties [redacted]
Eleven pip [redacted]
qualified b [redacted]
and by the [redacted]

CONCLUSIONS

Acciaierie d'Italia and Rina Consulting Centro Sviluppo Materiali are collaborating on the development of natural gas and hydrogen transport steels. CSM's typical approach for metallurgical design of pipe steels was adapted to the case of interest and used to define chemical composition and operating practices that allow to manufacture ERW pipes of grade X60ME, without exceeding 0.12% of the carbon.

Concerning to it, the results of the industrial test are satisfying for the validation of methodology and the pipes are in compliance with the ISO3183. However, in the future it might be interesting to further investigate the system to:

- reduce material yield strength, which is considered high even if in line with standard requirements;
- keep, or improve, Y/T values;
- contain the mechanical properties dispersion to avoid the risk of non-conformity;
- and test the material in hydrogen atmosphere.

REFERENCES

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[4] Pokutylowicz, Collins, Baragar, Yue: Properties-Prediction Model for the Hot Rolling of Long Products, 37th MWSP Conf. Proc., ISS, 1996, Vol. 33, pp427-431.

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