ISSN 1970-8734
Vol. 1 N. 4
July 2007

International Review of Mechanical Engineering (IREME)

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Praise Worthy Prize

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Effect of Different Rolling Schedules on the Mechanical Properties and Microstructure of C Mn (V-Nb-Ti) Pipeline Steel

A. Guedri[1, 4], D. Berdjane[2], S. Tlili[2], B. Merzoug[3], A. Zeghloul[4]

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***Keywords**: Controlled rolling; Controlled cooling; Processing parameters; Micro alloying; HSLA steel; Mechanical properties*

I. Introduction

The American Petroleum Institute (API) provides standards for pipe that are suitable for use in conveying gas, water, and oil in both the oil and natural gas industries. The API 5L specification describes the requirements of chemistry, tensile test characteristics and toughness behavior. The property requirements of steel vary depending on the particular application and operating conditions. The basic requirements, however, are high strength together with superior toughness at low temperature and excellent weldability. It is also important that steels should exhibit superior corrosion resistance, especially when petroleum and natural gases in recent years have become more of the type that contain wet H2S (source of sulfur). This had necessitated strict control of sulfur and phosphorus and cleanliness of steel, in general. In casting, the parameters of concern are solidification microstructure, segregation, strand guiding system, casting temperature and the cooling rate.

In the case of thin-slab casting, the higher solidification rate results in smaller dendrite arm spacing, significantly reduced micro- and macrosegregation and improved homogeneity [1]. Furthermore, the quality of the hot strips and its properties are determined by the rolling and cooling process parameters (pass schedule, cooling rate, recrystallization temperature), and the metallurgical events involved in recrystallization, grain coarsening, transformation, and the precipitation behavior [2]. Following the great progress of controlled rolling practice over the last two decades, accelerated cooling after hot rolling has currently been regarded as a further advanced thermomechanical treatment in hot rolling process. However, it is very important that HSLA steel plates with low cost and high quality can be manufactured using existing rolling mills in terms of thermomechanical processing or so-called thermomechanical control process. In general, thermomechanical control process of plates consists of both controlled rolling and accelerated cooling after hot rolling. So, the controlled rolling parameters (reheating temperature, reduction, deforming temperature, inter-pass time) and cooling conditions (cooling rate and finish-cooling temperature) play a particularly important role [3]. The aim of controlled rolling process of microalloyed steels is to obtain required properties by controlling the final microstructure. The final microstructure and mechanical properties depend strongly on the chemical composition, controlled rolling parameters and cooling conditions of the plate [5]. The present work is a laboratory study of the effects of the processing parameters on the microstructure and properties of standard pipeline grade X70 type API HSLA steel.

II. Experimental Procedure

The chemical composition of the steel used in this investigation is given in Table 1. The steel was supplied by the Elhadjar Iron and Steel Factory (Elh-ISF), Algeria. Plate-controlled rolling process followed by controlled cooling tests was carried out on laboratory rolling mill with 330 mm diameter rolls and rolling

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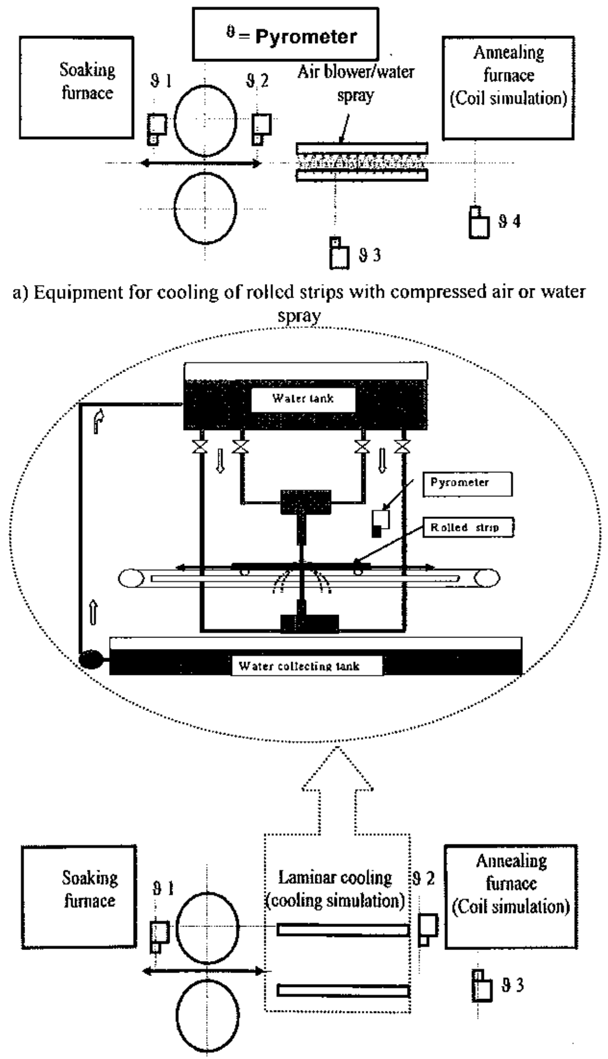
speed of 1m/s. In the present work, slabs (55x100x100) mm^3 were reheated at 1250°C for 30 min, and were rolled to 12-mm-thick plates with six to ten phases as two different rolling schedules (see Fig. 1).

II.1. Rolling, Cooling and Annealing Technology

The first schedule(I) consisted of six passes (finish rolling simulation only) with finish temperatures of 800°C,750°C and 700°C. The material was heated in a furnace; afterwards it cooled to rolling temperature in ambient air. After rolling, the steel was cooled by water spraying, compressed air and in ambient air to temperatures between 650°C, 600°C and 550°C. This was followed, as in the former experiments, by a holding on finish temperature for 2hours. New is, after the two hours of holding no cooling in ambient air to 20°C, but a furnace cooling to 300°C.



a) Equipment for cooling of rolled strips with compressed air or water spray

b) Equipment for laminar cooling of rolled strips

Fig. 1. Schematic diagram of basic concept of the laboratory equipment used for the experiments

Objection was to see possible effects of slower cooling rates on the properties after coiling. The program of this schedule can be seen below.

The schedule (II) was, more adapted to the real rolling conditions in (Elh-ISF). So it consisted of 5 roughing passes and of 5 finishing passes, all in all 10 passes. More passes were not possible because of the delivered raw material thickness of 55mm. The roughing passes laid at temperature between 1200°C and 1050°C, followed by cooling in ambient air and the finishing passes between 950°C and 800°C, res.750°C.After the rolling process two cooling systems were used: Laminar water cooling and cooling with compressed air.

After Rolling, annealing and cooling the samples were mechanic worked to get specimen for tensile tests, notch impact tests (at room temperature as at lower temperature of 0°C and -30°C with longitudinal specimen) and microstructure investigations.

TABLE I
CHEMICAL COMPOSITION OF SAMPLE (IN % WEIGHT)

C	Si	Mn	P	S	Cr	Mo
0,139	0,130	1,51	0,011	0,004	0,01	0,01
Al	N	Cu	Nb	Ti	V	Ni
0,0243	0.0211	0,026	0,075	0,024	0,041	0,01

II.2. Cooling Tests

Four different cooling systems were used, in order to simulate the rolling conditions in (Elh-ISF), as good as possible and to check the possibilities of improving the mechanical properties of steel X70. Thus way very different cooling rates were possible. At the rolling schedules (I) and (II), all experimental methods were in operation, so that a good comparison of the effects of the differing cooling methods and especially of differing cooling rates on the properties of the finished strip is possible. The real temperature in the centre of a finish rolled strip was always measured with thermocouples. Table2 gives an overview of the used cooling methods and cooling rates. As expected, laminar cooling shows the highest cooling rates (50K/s), followed by water spraying (21K/s). Compressed air brought not so high cooling rates (3,6 K/s),the lowest rates had cooling in ambient air (1,1K/s). The problem with the used configuration for water spraying was especially a strong reheating effect after the end of cooling. So a reheating of about 35K to 40K took place, which could have affected the properties of the final strips. At the other cooling systems, especially at laminar cooling, such a reheating effect was also seen, but of much smaller magnitude. Apparently at cooling with water spraying the strip was not cooled completely to the centre, though the pyrometer indicated the desired surface temperature, so that such a reheating could appear. A discussion of the results of different cooling systems (cooling rates) on the mechanical properties of the finish rolled strips will be appear later (see III.1.3.).

TABLE II
USED COOLING METHODS AND COOLING RATES OF ALL EXPERIMENTS

Cooling method	Rolling Schedule		Cooling rate between 800°C and 600°C
Ambient air	I		1,1 K/s
Compressed air	I	II	3,6 K/s
Water spray	I		21 K/s
Water Laminar cooling		II	50 K/s

II.3. Rolling Experiments

II.3.1. Rolling Schedule (I)

After rolling according to schedule (I) the strips were cooled by water spray or compressed air res. ambient air. Afterwards the specimens were kept two hours at coil temperature in a furnace. Alter this, the furnace was switched off and the rolled strips cooled in a longer time period within the furnace to 300°C. Later they cooled down to room temperature in ambient air. Fig. 2 shows graphically the temperature-time regime of rolling schedule (I) until the finish of cooling to coil temperature by water spray or air. In Fig. 3 the complete technological process can be seen. It starts with the withdrawal of the specimens after soaking and finishes with the extraction of the strips from the furnace after cooling to 300°C and following cooling in ambient air to 20°C. All in all it required 17h52mn20s to cool down to 300°C and 18h to reach 20°C. This is in a very good with the cooling times of a complete coil in (Elh-ISF).

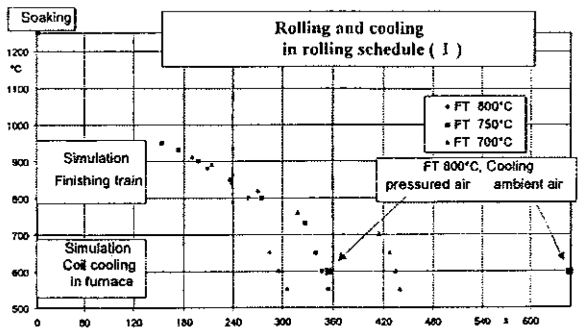


Fig. 2. Temperature-time regime at rolling in schedule (I), with water-spray / air cooling

II.3.2. Rolling schedule (II)

At rolling schedule (II), the roughing process needed 90 seconds (cooling of the strip after each pass in ambient air), finishing took place within 150 seconds.

The complete rolling process according to rolling schedule (II) took 237 seconds. Especially here was a longer interpass time of 50s at cooling of the strip in ambient air between roughing and finishing. This should simulate the transport of the strip from roughing mill to finishing mill. The simulation of coil cooling was finished after 7400s (2 hours holding at cooling temperature after finish rolling) Afterwards the strips were extracted from the furnace and cooled in ambient air. So the complete process ended after 11000s at a temperature of 20°C. Fig. 4 shows the temperature-time regime of die complete technological process according to rolling schedule (II) including simulation coil cooling in the furnace and afterwards cooling in ambient to 20°C. If we compare the temperature-time regime of rolling schedule (I) and(II), (see Fig. 3), so we realise the time differences of both rolling and cooling strategies (64800s at (I)and 11000s at (II)).

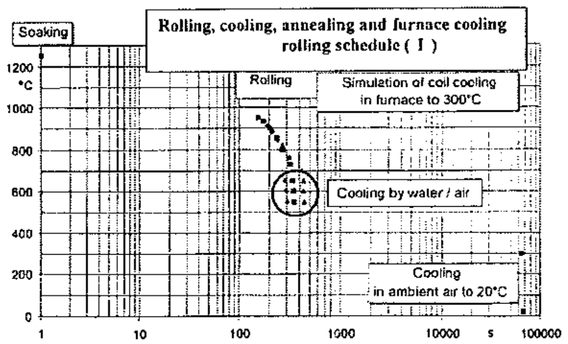


Fig. 3. Temperature-time regime of the complete technological process including furnace cooling at rolling schedule (I)

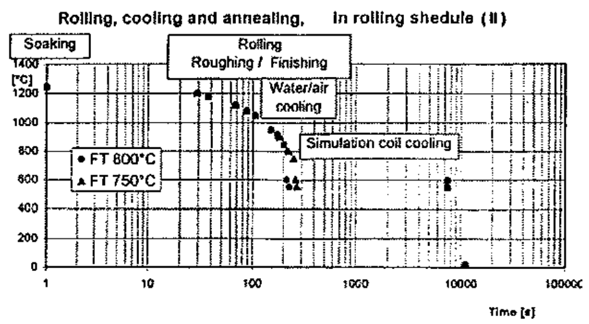


Fig. 4. Temperature-time regime of the complete technological process in rolling schedule (II)

III. Results and Discussion

III.1. Mechanical Properties

The reheating temperature, amount of reduction, rolling schedules, deforming temperature, inter-pass time, finish rolling temperature and cooling rate are important controlled rolling parameters affecting strength and toughness [3]. For the investigations of mechanical properties from each finish rolled strip were, depended on strip length or width, 2 or 3 tensile test specimen prepared and tested. Again the flat tensile specimen DIN 50 125 - E 10x25x90 was used.

III.1.1. Tensile Tests

III.1.1.1. Schedule (I)

The tests were made at the Institute of Material Sciences at TU Bergakademie Freiberg. A summary of the mechanical properties of the strips rolled according to rolling schedule (I) is shown in Table 3.

From this Table3 can be seen, that the yield strength R of all rolled strips fulfils the requests of norm API 5L for steel X70 (482MPa). Or in other works, that means for all investigated rolling conditions (finish rolling temperature of 800°C, 750°C and 700°C) that the type of cooling (water spray, compressed air and ambient air) did not affect the mechanical properties essentially. The tensile strength Rm is also in the range of norm API 5L (here the request is 565 MPa). The rolling conditions did affect less the tensile strength, but especially at low finishing and coil temperatures we see higher values. The data of the elongation in Table 3 show, that only two rolled strips with a finishing temperature of 800°C, cooled down by ambient air or compressed air to a coil temperature of 600°C were in the range of norm API 5L. The other values, all cooling with water spray, were out of API 5L. Here arises the question, if the elongation does not so much depend on finishing or coil (annealing) temperature, but on type of cooling. But if we see the different cooling systems within this project (ambient air, compressed air, water spray and laminar cooling), so appeared at water spraying one problem. The cooled strip reheated again after finish of cooling. The method of water spraying brought besides laminar cooling the highest cooling rates, but in combination with a reheating affect after the end of cooling, here began a new rise of temperature between 35K and at, 40K. So the real temperature after cooling was higher than expected. Immediately after water spraying also followed the transport to the annealing furnace (simulation coil cooling). Here the process of holding at finish cooling temperature started with higher values than expected. The strip had still to cool down in the furnace to the desired coil temperature and it should have needed a longer time period to catch the real finish/coil temperature. So it seems from this point of view, that the cooling rate is of much lower importance than the real finish/coil temperature after rolling. The other cooling systems, especially water laminar cooling, showed also a reheating affect, but of much smaller magnitude. Here was no affect on the later investigated mechanical properties.

Fig. 5 to Fig. 8 illustrate the correlation between finishing, coil temperature and mechanical properties of strips rolled according to the rolling schedule(I).This confirms the results of the former rolling programs, both low finish as low coil temperatures have a positive effect on yield and tensile strength. But the main effect on the mechanical properties is the coil temperature. By reduced coil temperatures the mechanical properties such as yield and tensile strength improve. So the best values of R and R_m were found at a finish temperature of 700°C and a coil temperature of 550°C. As in the experiments before, the relation R/R_m seems to find lower values at lower finish temperatures that mean, the finish temperature affects tensile strength R_m more than yield strength R. To reach a low coil temperature it is suggestive to adjust also a low finish rolling temperature. So both yield as tensile strength, could be improved by the same technological procedures [6].As described before, the elongation at water spraying did not reach the values of other cooling methods. This is especially seen in Fig. 7. The strips cooled to coil temperature in ambient air or with compressed air show a higher elongation than after water spraying. Apparently this is an effect of the discussed reheating phenomenon of the cooled strips after water spraying. The reduction of area after water spraying, also did not reach the results of other rolling and cooling technologies.

TABLE III
MECHANICAL PROPERTIES OF STRIPS ROLLED ACCORDING TO ROLLING SCHEDULE (I)

Strip N°	Temp. (°C) (Tf)	(Tb)	Cooling with	R MPa	Rm MPa	A (%)	Z (%)
A 1/2	800	600	Air	488	572	25,75	40,1
A 3/4	800	600	Press. Air	518	610	25,5	41,9
A 17/18	800	650	Water - Spray	517	605.5	18,75	42,2
A 11/12	800	600	Water - Spray	515	614	16,0	42,7
A 5/6	800	550	Water - Spray	519	622	17,0	44,7
A 19/20	750	650	Water - Spray	509	612	18,5	43,8
A 13/14	750	600	Water - Spray	520	620	18, 25	42,5
A 7/8	750	550	Water - Spray	522	626	19, 25	44,4
A 21/22	700	650	Water - Spray	516	626	18,0	47,8
A 15/16	700	600	Water - Spray	520	628	19,0	44,1
A 9/10	700	550	Water - Spray	524	638	17, 5	42,9

III.1.1.2. Schedule (II)

The rolling schedule (II) was characterized by finish rolling temperatures of 800°C and750°C, followed by laminar water cooling or cooling with compressed air to coil temperatures of 600°C and 550°C. Especially by the laminar cooling it was aspired to simulate the real rolling conditions in (Elh-ISF) as close as possible. The realized rolling and cooling conditions as the found mechanical properties are illustrated in Table4. With the rolling schedule (II), especially the distribution of reduction and temperature on the different passes, alone brought essentially better values. If we summarise all data in Table4, independent from the rolling conditions and cooling temperature, so we find especially for the tensile strength, 6% higher values after water laminar cooling than after cooling with compressed air. Nearly the same relations show the yield strength. This should be a result of the higher cooling rate (3,6K/s after cooling with compressed air and 50K/s after laminar cooling). Or in other works, the most effective cooling method is water laminar cooling, which brings also the best results in mechanical properties.

III.1.2. Toughness Tests

III.1.2.1. Schedule (I)

In the toughness tests, as before in the other investigations, ISO-V-notch impact test specimen (ISO-V- DIN 50 125) were used (dimensions 50x10x10mm, tested cross section 10x8mm).

TABLE IV
MECHANICAL PROPERTIES OF STRIPS ROLLED ACCORDING TO ROLLING SCHEDULE (II)

Strip N°	Temperature (°C) (Tf)	(Tb)	Cooling with	R (MPa)	Rm (MPa)	A (%)
1	800	611	Water	554,2	652	25
7	800	570	Water	554,2	691,7	24,5
11	750	606	Water	563,5	676	26,5
16	750	564	Water	562,5	685,4	25
2	800	606	Water	550	689,6	28
13	750	620	Water	556,2	660,4	25
3	800	600	Compressed Air	541,7	641,7	26
6	800	550	Compressed Air	560,4	687,5	26
12	750	600	Compressed Air	543,7	646,7	26,5
18	750	550	Compressed Air	564,6	669,8	28
4	800	600	Compressed Air	538,5	649	26
9	800	550	Compressed Air	541,7	653,1	24,5
14	750	600	Compressed Air	543,8	649	27
19	750	550	Compressed Air	545,8	645,8	25

Only longitudinal specimens were tested in a temperature range between 20°C and -30°C. Fig. 9 and Fig. 10 shows the average values of notch impact toughness after rolling according to the rolling schedule (I) at all test temperatures. As expected, the highest values of toughness were found at 20°C, at lower temperatures the toughness deteriorates. Cooling with compressed or in ambient air brought the best results, in contrast cooling after water spraying showed significant worse toughness. Also a low test temperature does not affect the relations of toughness after water spray and air cooling. But the requests of norm API 5L (65J at 20°C) were fulfilled by all rolling and cooling conditions of rolling schedule (I). Even the values of the tests at a temperature of -30°C would have fulfilled the requests of the norm for 20°C. A steep fall of toughness was not found up to -30°C, but the former experiments showed, that this starts first at lower temperatures. The influence of finish rolling and annealing temperatures (simulation coil cooling) on toughness at 20°C, 0°C and -30°C is illustrated in Fig. 9 and Fig. 10.The values vary within smaller ranges. After cooling with water spray the whole sequences of finish temperatures (800°C, 750°C and 700°C) as well as the different coil (annealing) temperatures (650°C, 600°C and 550°C) show very small variations of toughness. The differences are reduced further at low test temperatures as 0°C and -30°C. The best toughness at rolling according to the schedule (I), showed strips with cooling in ambient air or in compressed air.

III.1.2.2. Schedule (II)

After rolling according to the rolling schedule (II) the toughness tests, like those in schedule (I), were made with longitudinal specimen at test temperatures of 20°C, 0°C and -30°C. The results are assembled in Table 5.The found toughness fulfilled all the norm API 5L, independent from rolling and cooling technology.

TABLE V
LOW TEMPERATURE TOUGHNESS OF STRIPS ROLLED ACCORDING TO ROLLING SCHEDULE (II)

Strip N°	Temperature (°C) Fin (FT)	Coil (CT)	Cooling with	Toughness longitudinal (J) 20°C	0°C	-30°C
1	800	611	Water	143,9	121	93,4
7	800	570	Water	139	125,6	84,6
11	750	606	Water	140,5	116,8	75,6
16	750	564	Water	145	115	78
2	800	606	Water	135,7	124,3	78,2
20	800	540	Water	106,9	72,2	47,3
13	750	620	Water	144,6	127,8	69,2
21	750	545	Water	85,1	64,8	54,7
3	800	600	Comp.Air	125,3	106,8	92,3
6	800	550	Comp.Air	129,5	120	78
12	750	600	Comp.Air	131,2	114,5	75,6
18	750	550	Comp.Air	137,4	105,8	74,8
4	800	600	Comp.Air	141,4	121,4	67,6
9	800	550	Comp.Air	145,2	140,2	94,1
14	750	600	Comp.Air	144,2	129,6	94
19	750	550	Comp.Air	96,6	88,8	56,2

Remarkable and hardly explainable, considering the former results, are some low toughness after a finishing temperature of 750°C and a coil temperature of 550/545°C both after laminar as after cooling with compressed air.

III.1.3. Effects of Different Cooling Systems on Mechanical Properties

Four different cooling systems were tested, to see the effects of varied cooling strategies on the mechanical properties of steel X70 and to simulate the practical cooling and coil conditions in (Elh-ISF) as close as possible. Right from the start of the investigations besides cooling in ambient air also a compressed air cooling on both rides of the rolled strip was used. With

the cooling rate of about 3,6 K/s could be realized, compared with 1,1 K/s at cooling in ambient air.

So a water spraying system was developed. This worked like the used system for cooling with compressed air and brought cooling rates of about 31K/s. But the experiments with water spray cooling showed also, that after finish of cooling a reheating affect appeared. The cooled strip heated again, using the residual heat. To avoid this and to simulate the practical conditions in (Elh-ISF) as close as possible with cooling rates of about 50K/s. For these purposes the mechanical properties depending on finish and cool temperature and especially on the cooling rate were assembled. This is illustrated in Fig. 11 and 12. As we can see at the mechanical properties of steel X70, the cooling rate is of lower weight, but water laminar cooling brought the best results.

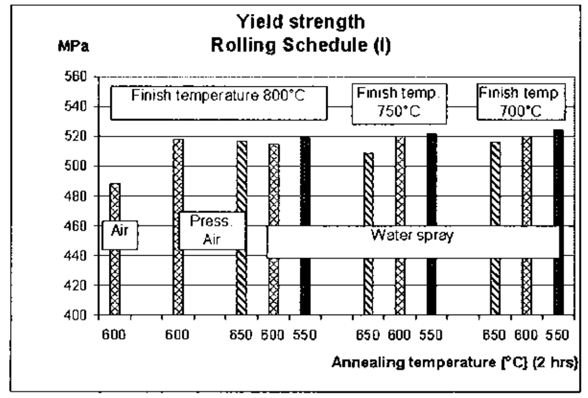


Fig. 5. Influence of finish and coil temperature on yield strength, water spraying

So the yield strength of the finish rolled and cooled strip improves beginning from cooling in ambient air over water spraying and compressed air to laminar cooling. If we observe the cooling rate only, water spraying (31K/s) brought better values than compressed air (3,6K/s) and lay beside laminar cooling (50K/s).

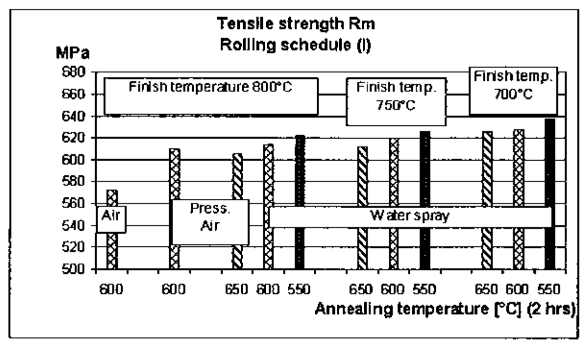


Fig. 6. Influence of finish and coil temperature on tensile strength, water spraying

But this isn't so. An explanation for this phenomenon should be the already discussed reheating phenomenon of the cooled strip after water spray cooling. On the other hand does this mean that the achievement of a precise cooling temperature is of more importance than the cooling rate. The cooling rate affects the properties relatively low, if we compare the results of tensile tests in Fig. 11. So, the yield strengths after cooling in ambient air and laminar cooling do not differ substantially (13,5% only). Concerning the tensile strength we see the same relations (14%).Amazing are the high values of elongation after cooling in ambient air.

Here water spraying brought the lowest values, which differ to a maximum of 36%compared to either compressed air or laminar cooling. Concerning the toughness, (Fig. 12), cooling in ambient air brought at all test temperatures good results. Here also a cooling with water spray showed the lowest data. That does not also change at low test temperatures of 0°C or -30°C.

If we see all tested mechanical properties (tensile and toughness) as an entity, so the best results for steel X70 were found after laminar cooling, especially at finish cooling temperatures below 600°C.

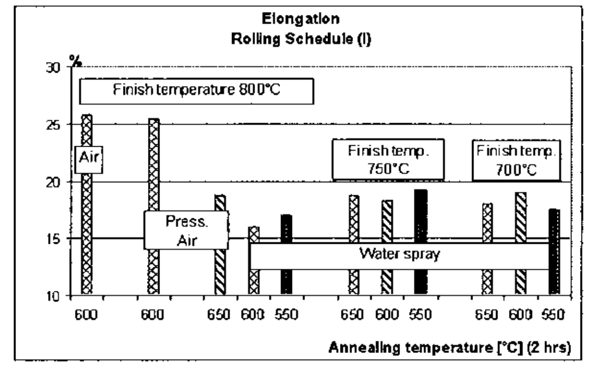


Fig. 7. Influence of finish and coil temperature on elongation, water spraying

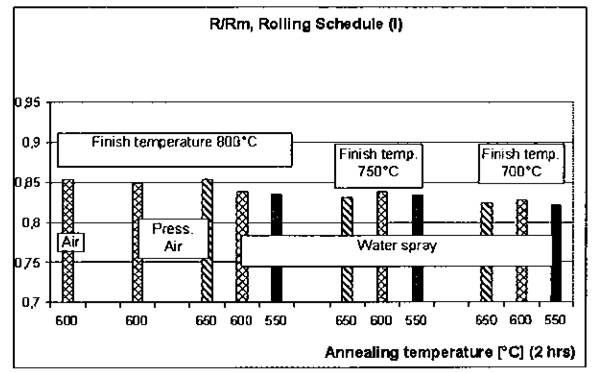


Fig. 8. Influence of finish and coil temperature on relation yield strength to tensile strength, water spraying

III.2. Microstructure

In order to estimate the existing grain size very precisely, for the microstructure investigations of each rolled strip one specimen was extracted and prepared. In an area of 10mmx10mm, 6 to 8 micrographs were taken and the grain size measured. The grain sizes of all rolled strips according to rolling schedule (II) do not differ very much, see Fig. 13(a, b) below. It is observed that the ferrite grain refinement is mostly the result of the deformed austenite below the recrystallization temperature and accelerated cooling after deformation; both processes increase the nucleation of ferrite phase [7]. Several increase mechanisms of nucleation rate of ferrite by deformation have been put forward.

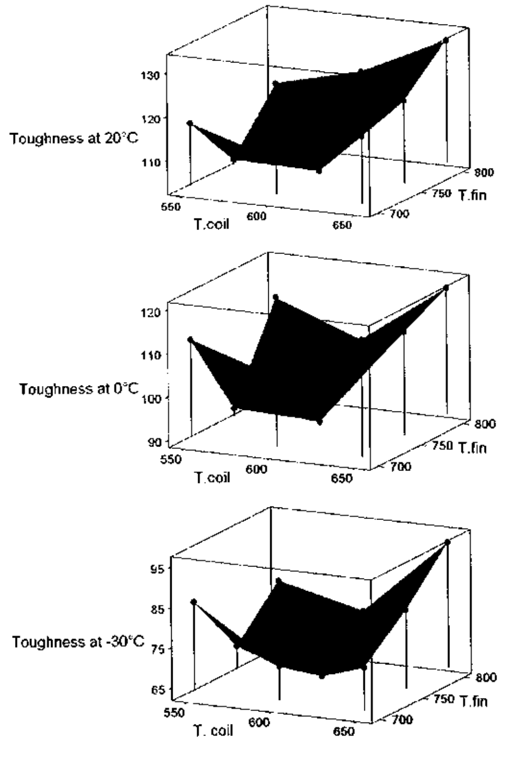


Fig. 9. Influence of finish and coil temperature on toughness, water spraying

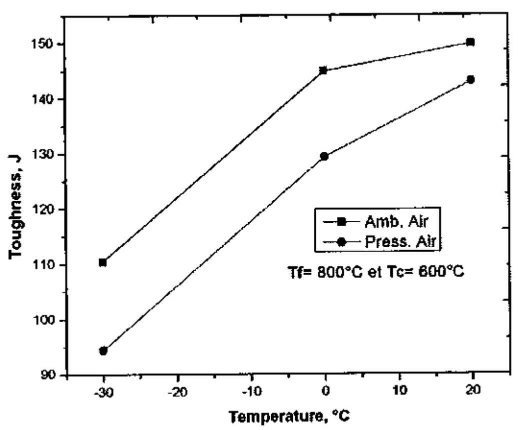


Fig. 10. Influence of finish and coil temperature on toughness, ambient and compressed air

TABLE VI

GRAIN SIZE (μm) FOR LAMINAR COOLING (STRIP 7AND16) AND COMPRESSED AIR COOLING (STRIP 14 AND 19)

Strip	7	16	14	19
Ferrite grain size	6,8	6,5	6,1	6,6
Finish rolling temperature	800	750	750	750
Coil temperature	570	564	600	550
Annealing 2hrs at	550	550	No annealing after cooling	
Fig 14	c	d	a	b

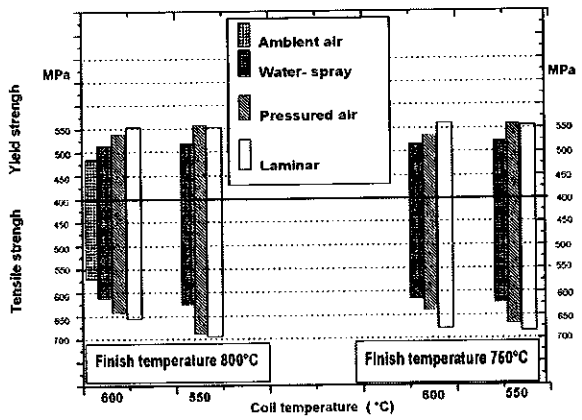


Fig. 11. Effects of different cooling technologies on yield strength, tensile strength

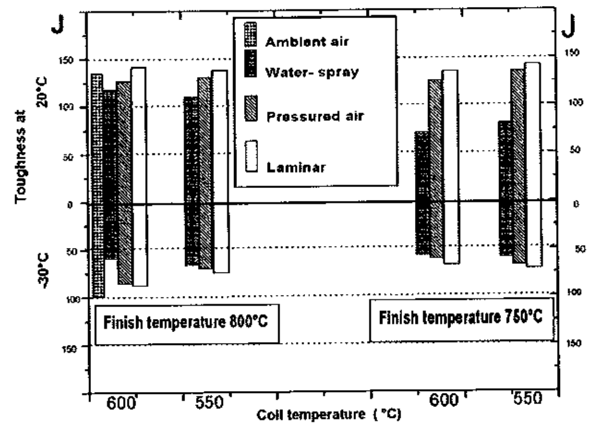


Fig. 12. Effects of different cooling technologies on toughness

These include an interrelation between the increased nucleation rate of ferrite with the:

a. bulges formed by local austenite grain boundary migration [8],
b. formation of subgrains near the deformation austenite grain boundaries, and
c. strain energy of the dislocations stored in deformed austenite [9].The grain refinement is obtained by control of the rolling conditions time, temperature and deformations during the whole production process.

Grain refinement in steels is enhanced through a combination of controlled rolling and microalloying.

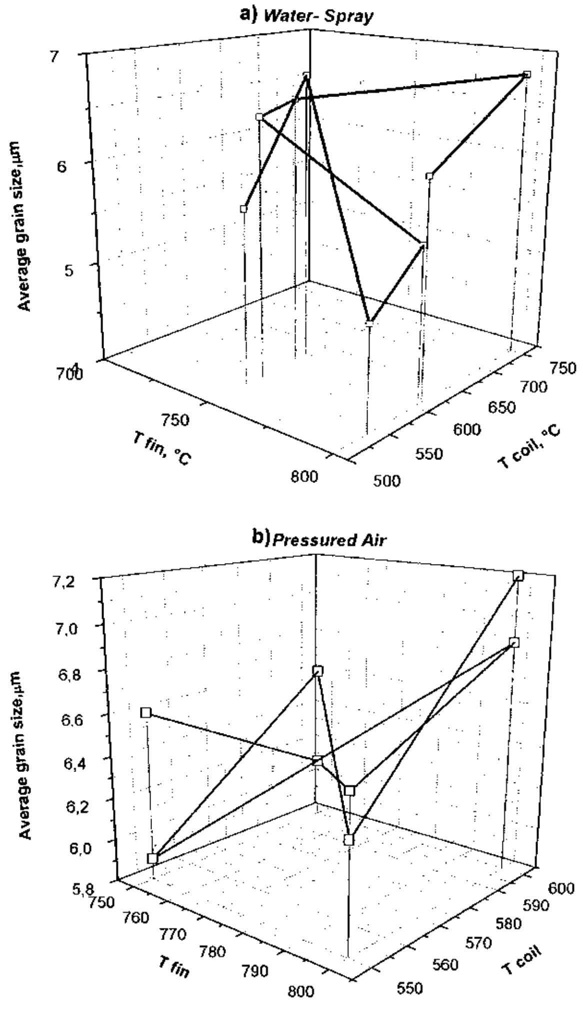


Fig. 13. Average grain size of strips rolled according to schedule (II) a) Water spray, b) Compressed air

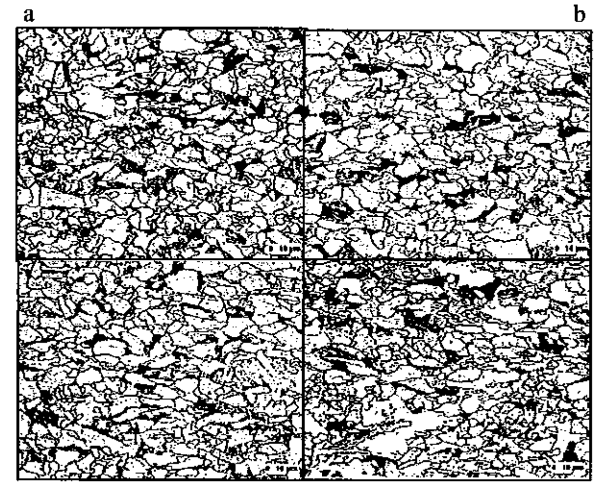


Fig. 14. Micrographs of selected strips: 7, 14, 16 and 19

The primary grain refinement mechanism in controlled rolling is the recrystallization of austenite during hot deformation. Small additions of alloying elements like Nb, V and Ti result in the formation of carbonitrides in the microstructure. These very fine precipitates are effective in preventing grain growth. By the use of controlled rolling, recrystallization is retarded during the last passes. The average grain sizes after rolling according to the rolling schedule (II) was found between 5,0 and 7,2μm. The different finish rolling temperatures as cooling strategies didn't affect much the grain size as the shares of recrystallized phases. Here the phase proportions were not investigated in detail. The Fig. 14 show exemplary micrographs of selected strips, commented in Table 6.

IV. Conclusions

In experimental investigations the deformation conditions at hot strip rolling should be simulated. Objection was a corporate optimisation of rolling technology, to create advantageous microstructures and to improve the mechanical properties of the finished strip. The investigated material is used for weldable pipelines. Within this work the following investigations were:

- Investigation of 4 different cooling technologies (ambient air, compressed air, water spray and water laminar cooling),
- Different simulations of coil cooling after rolling (annealing in a furnace), with holding times between 10 minutes and 24 hours,
- Metallographic investigations of most rolled strips
- Tensile tests, (yield strength, tensile strength, elongation and reduction of area)
- Toughness tests between 20°C and -30°C, longitudinal and partly transverse,

The finish temperature of the rolling experiments was verified between 850°C and 700°C. The results of all in laboratory with different technologies rolled strips confirmed the conclusions, which were also found at the investigations of strips rolled in (Elh-ISF), that a reduced finish temperature improves mechanical properties of the final strip as yield strength and tensile strength. But the finish rolling temperature affects the mechanical properties only slightly.

Of far greater importance on the quality of the hot strips is the coil temperature. Different coil temperatures were simulated in the experiments by varying heat treatment temperatures in a furnace (between 500°C and 630°C) res. annealing times (between 30 minutes and 24 hrs) alter finish rolling. All rolling experiments showed, that at a reduced coil temperature improves both yield strength as tensile strength and reduction of area.

The relation between yield strength and tensile strength was not affected essentially. Where as the elongation marginal deteriorated at low coil temperatures. Maximum yield strengths of about 560 MPa were reached, as maximum tensile strengths of about 675 MPa. Few strips with a low coil temperature of 550°C showed no yield strength, but tensile strength of more than760MPa. These strips had also a deterioration of elongation and toughness. So coil temperature at 550°C or below are not recommendable. As result of all investigations a possible finish rolling temperature for steel X70 between 850°C and 830°C is proposed. These would result in a coil temperature of about 560°C.So an optimum balance between strength and toughness properties should be found. The restrictions of roughing, finishing and coil temperatures would also reduce the partly large range of properties of different strips. The average grain sizes after rolling was found between 5 and 7,2µm. The different finish rolling temperatures as cooling strategies didn't affect much the grain size as the shares of recrystallized phases.

Acknowledgements

The authors would like to express their gratitude for the financial support by CERCIM/SIDER Center. Experiments on the thermomechanical simulator were performed at Freiberg University, which is gratefully acknowledged.

References

[1] R. Kaspar, Steel Res. 75 (2003) 318–326.

[2] C.P. Reip a. and al , High strength microalloyed CMn(V–Nb–Ti) and CMn(V–Nb) pipeline steels processed through CSP thin-slab technology: Microstructure, precipitation and mechanical properties. *Materials Science and Engineering A 424 (2006) 307–317*

[3] Y. Shunfa, C. Gouping, C. Meifang, *HSLA steel metallurgy and applications, Int. Conf. on HSLA Steels,* ASM, Metals Park, OH, 1986, pp. 213– 218.

[4] Adem Bakkaloglu, Effect of processing parameters on the microstructure and properties of an Nb microalloyed steel. *Materials Letters 56 (2002) 263– 272.*

[5] E.V. Pereloma, J.D. Boyd, Mater. Sci. Technol. 12 (1996) 1043–1050.

[6] Y. Shunfa, C. Gouping, C. Meifang, *HSLA steel metallurgy and applications, Int. Conf. on HSLA Steels,* ASM, Metals Park, OH, 1986, pp. 213– 218.

[7] S. Tlili, D. Berdjane, R. Benchouieb, G. Goldhahn : *Rapports techniques des travaux expérimentaux pour l'optimisation des propriétés mécaniques Sider lors du laminage à chaud des aciers microalliés,* document interne DRA/Freiberg, 1998-1999.

[8] G.R. Speich, in: A.R. Marder, J.I. Goldstein (Eds.), Proc. Int. *Conf. on Phase Transformation in Ferrous Alloys,* TMS-AIME, Warrendale, PA, 1984, pp. 341– 389.

[9] A. Sandberg, W. Roberts, in: A.J. DeArdo, G.A. Ratz, P.J. Wray (Eds.), Conf. Proc. TMS-AIME, Warrendale, USA, 1982, pp. 405– 431.

[10] A.K. Sinha, *Physical metallurgy of microalloyed high strength low alloy steels,* Proceedings of the Emerging Technologies for New Materials and Product-Mix of the Steel Industry, Cincinnati, OH, 1991, pp. 195.

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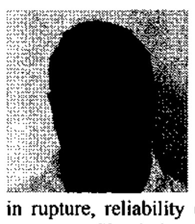

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Praise Worthy Prize

International Review of Mechanical Engineering (I.RE.M.E.), Vol. 1, n. 4
July 2007

Continuum Based Solid–Shell Element Modeling for the Optimization of Composite Multilayered Structures

M. Hannachi, H. Naceur, J. L. Batoz

Abstract – *In this paper a general methodology for modeling and optimization of material composite multilayered shell structures is proposed. It is based on the coupling between solid-shell finite element modeling and response surface method. The first part of the paper is devoted to the general FE formulation of the present composite 8–node brick solid-shell element called SCH8γZ7, based only on displacement degrees of freedom. A particular attention is given to alleviate shear, trapezoidal and thickness locking. The anisotropic material behaviour of layered shells is modeled using a linear elastic orthotropic material law for each layer. In the second part of the paper, we focus on an adaptive response surface method for the optimization problem. The response surfaces are built using moving least squares approximations and design of experiments. Applications to laminate thick shell structures are studied to validate the methodology, and good results have been obtained in comparison with ABAQUS® commercial code.* ***Copyright © 2007 Praise Worthy Prize S.r.l. - All rights reserved.***

***Keywords**: 3D–shell formulation, Composite structures, Optimization, Response Surface Model*

Nomenclature

$\mathbf{x}_0$ position vector at the mid surface
$\mathbf{x}$ position vector at a distance z to the mid surface
N_i shape functions
$\mathbb{F}$ deformation gradient tensor
$\mathbf{a}_{i\zeta}$ covariant basis vector
$\mathbf{a}^i_\zeta$ dual basis vector
$\mathbb{Q}$ orthonormal basis tensor
$\mathbb{L}$ displacement gradient tensor
$\mathbb{L}_\zeta$ displacement gradient tensor in parametric space
$\boldsymbol{\varepsilon}_c$ covariant strain tensor
$\boldsymbol{\varepsilon}$ curvilinear strain tensor
$\tilde{\mathbb{C}}$ transformation tensor (covariant to curvilinear)
$\mathbb{H}$ orthotropic material tensor
$\mathbf{m}_i$ orthotropic elastic material direction
$\tilde{\mathbb{H}}$ material tensor in convective coordinates
$\mathbb{R}$ transformation tensor (global to material)
$\boldsymbol{\sigma}$ Cauchy stress tensor
W_{int} internal virtual work
W_{ext} external virtual work
$\mathbf{u}$ displacement vector
$\mathbf{f}_s$ surface traction forces
$\mathbf{f}_v$ volume traction forces
h shell thickness
$\mathbb{k}$ shell stiffness matrix
$\mathbf{x}$ design variable vector
$f(\mathbf{x})$ objective function
$g(\mathbf{x})$ constraint function

I. Introduction

Thin structure models, even if they are often effective, have some disadvantages. Moreover, several problems appear when shell elements are used in combination with solids. In this case, transition elements are essential to bind shell elements with solids having different degrees of freedom (to connect rotations and displacements). Therefore, it becomes obvious to develop general-purpose and effective brick elements, able to deal with any type of structures (solid, shell, and/or their combination).

Solid-shell elements are a variety of finite element models midway between solid elements and thin shells. They have the same freedom configuration of solid elements but account for shell-like behavior in the thickness direction.

They are useful for modeling shell-like portions of a 3D structure without the need to connect solid element nodes to shell nodes.

Solid-shell elements have many advantages compared to the degenerated shell models, because of their kinematics simplicity, their ability in modeling industrial structures generally composed of bulk and thin-walled regions and also special rotations treatment in geometric nonlinear analysis can be avoided. Unfortunately, the formulation of valid solid-shell elements is more complicated than the one used for degenerated shell elements since solid-shell elements

Manuscript received and revised June 2007, accepted July 2007

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€ 40,00

1970-8734(200707)1:4;1-O

ISSN 1970-8734
Vol. 1 N. 6
November 2007

International Review of Mechanical Engineering (IREME)

Contents:

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International Review of Mechanical Engineering (I.R.E.M.E.), Vol. 1, n. 6
November 2007

An Artificial Neural Network Model for Predicting Mechanical Properties of CMn (V-Nb-Ti) Pipeline Steel in Industrial Production Conditions

A. Guedri[1,4], S. Tlili[2], B. Merzoug[3], A. Zeghloul[4]

Abstract – *The mechanical properties of API X60/X70 microalloyed steel were investigated with industrial thermomechanical experiments. The many parameters of processes obtained during production of the plant were systematically changed to optimise the strength and toughness properties. The optimised parameters were used for the production of the API X60/X70 steel. However, it is not easy to determine as to what parameters under which conditions influence the mechanical properties of the material. Therefore, in this study, a generalised regression neural network was developed to predict the mechanical properties as a function of experimental conditions. The predicted values of the yield and tensile strengths using the neural network are found to be in good agreement with the actual values from the experiments.* ***Copyright © 2007 Praise Worthy Prize S.r.l. - All rights reserved.***

Keywords: *Microalloyed steel; Mechanical properties; Artificial neural network; regression neural network*

I. Introduction

The idea of the development of pipeline steels with high yield strength and toughness [1]-[3] was based on user demands towards improvement in weldability and reduction of welding costs, especially during the construction of the pipelines [4]-[15]. In modern pipeline technology, both high strength and toughness are of primary interest [16]-[19]. The appropriate selection of microstructure is an important factor to further improve the weldability, strength and toughness behaviors of the oil and gas pipeline steels [20]-[24].

Thermomechanical processing is known to improve the mechanical properties of a material. In the case of high grade steels, application of this process minimizes, and sometimes even eliminates the heat treatment and thus saves energy. So, in high-strength low-alloy (HSLA) steels; thermomechanical controlled processing (TMCP) is a widely used process. To achieve the required microstructure and mechanical properties of thermo mechanically processed HSLA steels, it is necessary to have knowledge about the role of composition and process parameters. The chemistry of the steel and the TMCP parameters, like reheating temperature, amount of deformation in different stages of rolling, the finish rolling temperature and the cooling rate are known to exert appreciable influence on the structure and property of the finished product. It is known that the patterns relating the inputs and outputs in TMCP steels are qualitatively recognized by the experts in the field of metallurgy [25].

There has only been a limited effort in the formulation of a suitable model, which can determine the response variables quantitatively from a given set of input variables.

Although regression analysis is sometimes carried out to best fit a set of data to a specified relationship, its main drawback lies in the fact that the correlation between the input (composition and process parameters) and the output (mechanical properties) is to be pre-chosen without much reasons. Artificial neural network (ANN) is a kind of learning system, which maps the existing input–output relationship in a more precise way [26]. It is capable to accommodate the non-linearity of the relationships existing among the variables. Attempts have been made earlier to model the mechanical properties of HSLA steel by means of neural networks [27]–[30]. It has been noticed that the performance of ANN models, in terms of the achievable error level in least computational time, is essentially determined by a successful optimization of the number of neurons in the network, effective algorithms for accurate prediction and suitable transfer function. But the main criticism faced by the concept of artificial neural network is that the relation it develops between the inputs and outputs are mostly unknown to its user. The learning process of the network is inside a 'black box'. Though suitably designed networks are capable of making accurate predictions after being appropriately trained, it is not at all clear if the learning envisaged in the network has any similarity with that of a materials scientist. It is also not known whether the process of prediction used by the trained neural network makes use of the elemental

Manuscript received and revised October 2007, accepted November 2007

knowledge acquired by a scientist in respect of the effects of composition and process variables on the strength properties of thermo mechanically processed HSLA steel. Since mapping of input–output relationships for a given problem is mathematically feasible even without the understanding of scientific reasoning behind the phenomenological relationships between the input and the output, it is possible for such models to predict output values from a given set of fresh inputs.

This paper presents the prediction of strengths using a generalized regression neural network. The inputs of the network are the specifications of the process. The neural network developed in this study has succeeded in predicting tensile and yield strength. As stated in [31], artificial neural networks are very effective modern analytical tools to develop models for predicting mechanical properties of materials. In this study, general information about neural networks is given in the following; then a brief theoretical background of generalized regression neural networks is presented.

II. Neural Network Modeling

Regression analysis is familiar to scientists as a tool to fit experimental data empirically. The linear relationship is chosen before the best-fit coefficients are derived. The general form of the equation developed using linear regression is a sum of the inputs multiplied by a corresponding coefficient or weight (w_i) and added with a constant (θ). The developed linear equation may contain non-linear terms, forming a pseudo-linear equation. In linear regression models the relationship between an input and output tends to be linear and applies across the entire span of the input space, which may not be reasonable. A neural network is a general method of non-linear regression which avoids the difficulties occurs in linear regression technique. In this Chapter the fundamentals of neural networks and procedure followed to develop models are discussed.

II.1. Neural Network

A neural network is a general method of regression analysis in which a very flexible non-linear function is fitted to experimental data. When compared with linear regression analysis, a neural network is a non-linear regression by introducing another node which is hidden between input and output as shown in Fig. 1. Similar to linear regression method the input variable (x_i) is multiplied by weight (w_i), but the sum of all these products forms the argument of another transfer function, in this present work it is hyperbolic tangent as in equation (2). The final output is defined as linear function of hidden nodes and a constant, equation (1). Thus, the dependent variable y is defined as:

$$y = \sum_i w_i^{(2)} h_i + \theta^{(2)} \tag{1}$$

where h_i *are* defined as;

$$h_i = tanh\left(\sum_j w_{ij}^{1} x_j + \theta_i^{(1)}\right) \tag{2}$$

where (x_i) are the variables on which the output y depends, (w_i)are the weights (coefficients) and (θ_i) are the biases (equivalent to the constants in linear regression analysis). The combination of equation (2) with a set of weights, biases, value of i and the minimum and maximum values of the input variables defines the network completely as shown in Fig. 1. The availability of a sufficiently complex and flexible function means that the analysis is not as restricted as in linear regression where the form of the equation has to be specified before the analysis. The strength of the hyperbolic tangent transfer function is determined by the weight (w_i), the exact shape can be varied by altering the weights. The shape of the hyperbolic transfer function will be varied according to the availability of data in the input space. A model with one hidden unit in Fig. 2(a) may not be sufficiently flexible to capture the information from the database; however non-linearity can be increased by combining several of the hyperbolic tangents as shown as Fig. 2(b) .The neural network can capture interactions between the inputs because the hidden units are nonlinear. The nature of these interactions is implicit in the values of the weights, but the weights may not always be easy to interpret. For example, there may exist more than just pair wise interactions, in which case the problem becomes difficult to visualize from an examination of the weights. A better method is to actually use the network to make predictions and to see how these depend on various combinations of inputs.

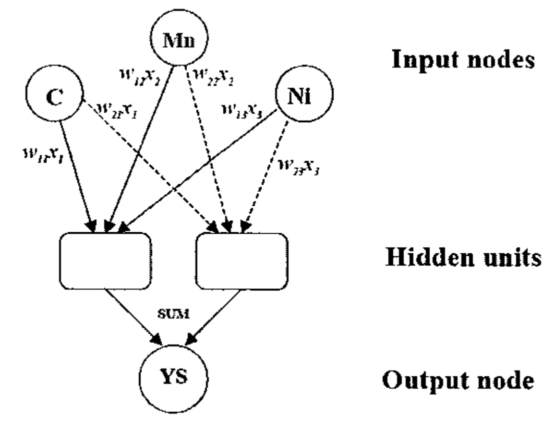


Fig. 1. Schematic illustration of input, hidden and output layers of neural network model

II.1.1. Error Estimation

The input parameters are generally assumed in the analysis to be precise and it is normal to calculate an overall error by comparing the predicted values (y_j) of the output against those measured (t_j), for example:

$$E \propto \sum_{j} \left(t_j - y_j\right)^2 \quad (3)$$

E is expected to increase if important input variables have been excluded from the analysis. Where as *E* gives an overall perceived level of noise in the output parameter, it is, on its own, an unsatisfying description of the uncertainty of prediction.

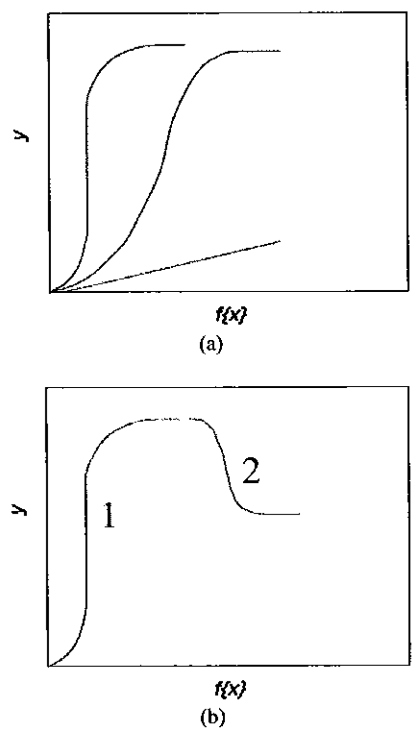


Fig. 2. Hyperbolic tangent relation between inputs x and output y, a) single flexible hyperbolic tangent with varying weights b) combination of tow tangents

II.1.2. Over Fitting

A potential difficulty with the use of powerful non-linear regression methods is the possibility of over fitting data. To avoid this, the experimental data can be divided into two sets, a training dataset and a test dataset. The Fig. 3 illustrates different degrees of complexity in fitting the training dataset and the test data. A linear model is simple and does not capture the real information form the data. An over complex model fits all the data in the training dataset, but badly generalized. The optimum model which is a generalized model captures real complexity in the database.

The model is produced using only the training data. The test data are then used to check that the model behaves itself when presented with previously unseen data. The training error tends to decrease continuously as the model complexity increases. In Fig. 4 the first diagram shows plotted points on an *x-y* axis. The neural network has to decide whether a line of best fit is complex enough, or a line through all the points is more appropriate. The second diagram shows that the training database will gradually set the function go through all the data points, hence reducing the overall error. However, the testing database can detect when the function is "overfitting", when it goes beyond the minimum on the test error curve [32].

II.2. Optimization of Architecture

The relations between input and output is rather complex and is greatly nonlinear. Greater nonlinearity may be introduced into a model by combining several transfer functions. This permits the neural network to capture nonlinear relationships almost arbitrarily. The number of transfer functions is the number of hidden units.

Because the number of hidden units is related to the complexity of the model and also because the availability of a sufficiently complex but flexible function effectively captures interactions between inputs, it is needed to optimize the number of hidden units and the number of hidden layers in the ANN to be used so that a good approximation of input–output relation is envisaged.

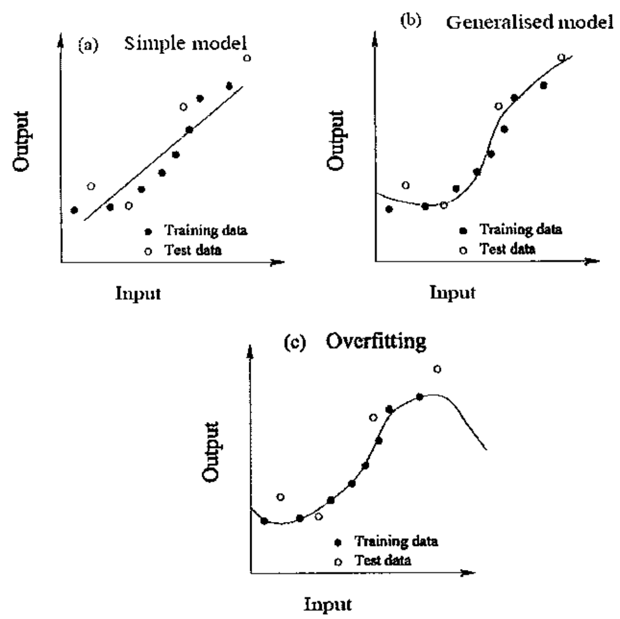


Fig. 3. Different degrees of complexity of fitting an input and output in a model

II.2.1. Selection of Transfer Function

Although it has been described by the previous workers that owing to the attainable flexibility, hyperbolic tangent function is most suitable for modelling metallurgical problems, logarithmic sigmoid function is also tried [33]; in order to verify the efficiency of the function in terms of describing the same problem of thermo mechanically processed steels. The result is that hyperbolic tangent function is superior to sigmoid function in respect of learning with less training error.

II.2.2. Selection of Training Algorithm

The training process involves the continuous adjustment of (w_{ij}), values by a suitable back propagation algorithm until the error level falls under a predetermined value. A large number of back propagation algorithms have been proposed [34]–[39]. In the present work, both back propagation and Levenberg–Marquardt algorithms [40] are used for training the optimized network.

III. Database

The database used for training and testing the differently designed custom networks comprise of the chemical composition (viz. weight percentage of carbon (*C*), manganese (*Mn*), silicon (*Si*), aluminum (*Al*), sulphur (S), molybdenum (*Mo*), phosphorus (*P*), niobium (*Nb*), titanium (*Ti*), and vanadium (*V*)), being subjected to TMCP of fixed process parameters like slab reheating temperature of 1200°C, deformation at the recrystallization temperature range and unrecrystallized temperature range, and the changed TMCP parameters are used as the input variables and the tensile and yield strengths are taken as the output variables.

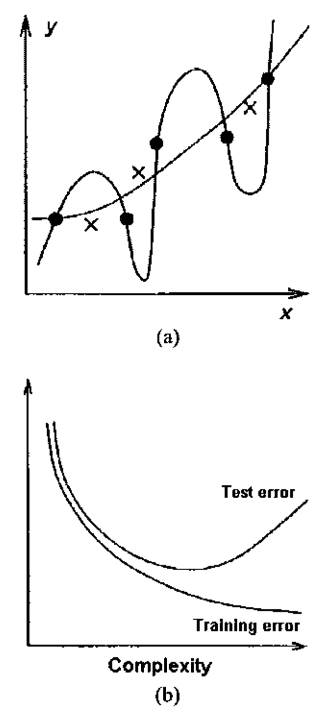
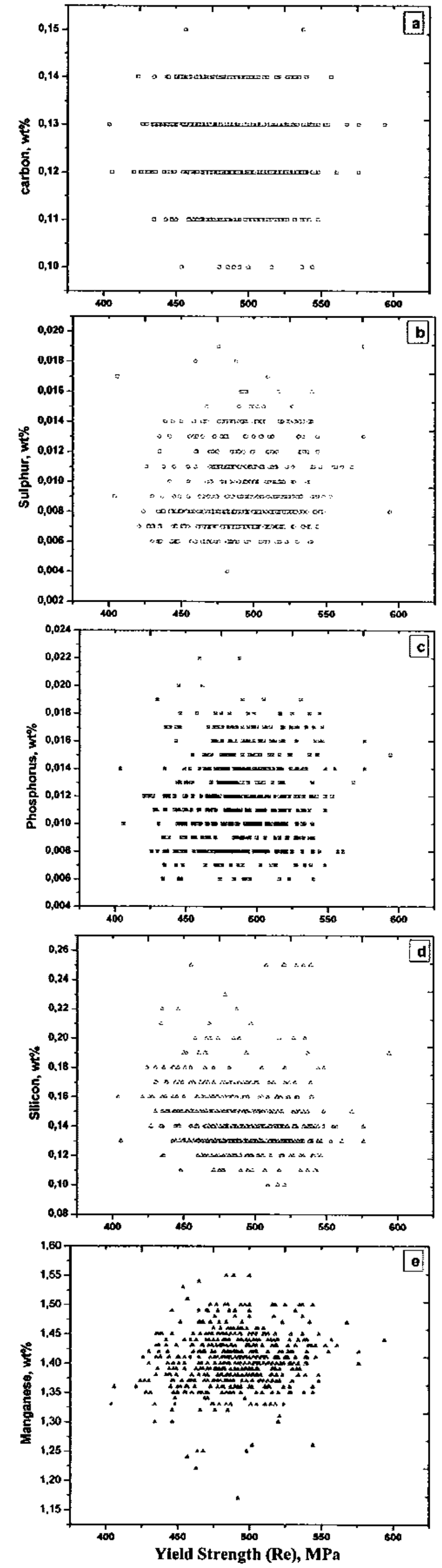
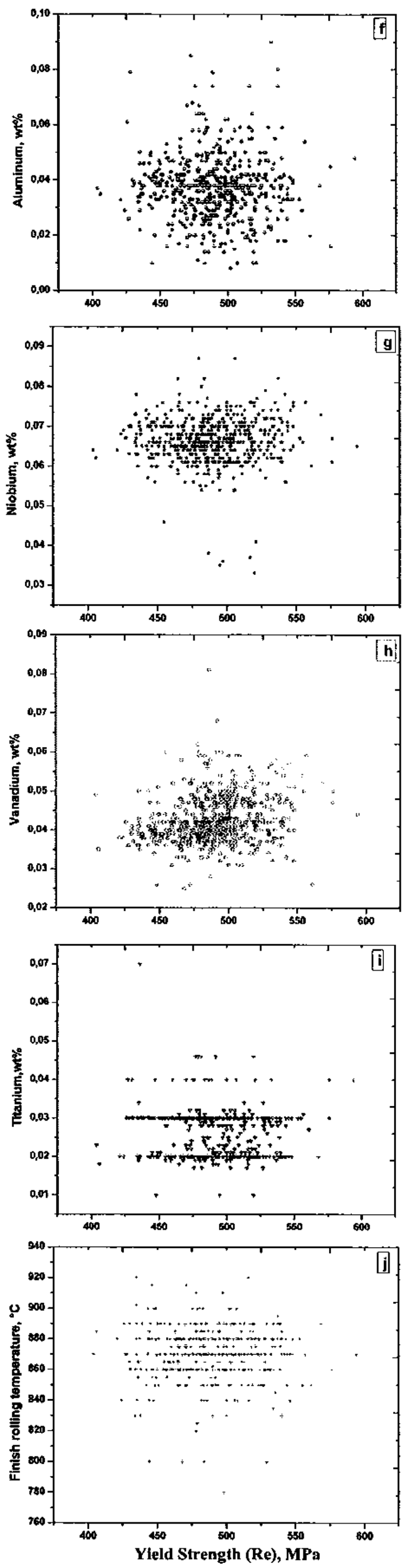


Fig. 4. Ranking procedure of trained models with varying model complexity

The data used for the present exercise have been mostly generated in the industrial hot rolling mill. The chemical analyses are done in atomic spectrometer. The mechanical testing has been carried out in Zwick modified machine. The ranges of variables used in the present work are listed in Table I and shown in Fig. 5 ((a) to (k)).





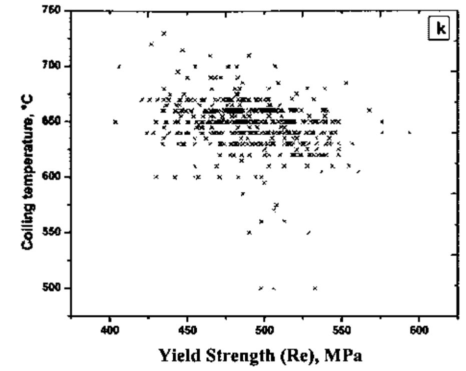


Fig. 5 (a to k). The database values of each variable versus the yield strength

Each variable is normalized within the range of 0–1 for ANN modelling by the operation given below:

$$x_N = \frac{x - x_{min}}{x_{max} - x_{min}} \quad (4)$$

where x_N is the normalized value of a variable x, x_{max} and x_{min} are the maximum and minimum values of x, respectively.

IV. Results and Discussion

For development of the model, a data set was constructed having 293 input and output pairs from the experiments. Seventy percent of the input and output pairs were selected randomly for training set and the remaining thirty percent of the pairs were assigned for test set. The weights in artificial neurons are adjusted during a training procedure to obtain the output parameter from the input parameters.

TABLE I
THE MINIMUM AND MAXIMUM LIMITS OF THE PARAMETERS

Parameters	Minimum	Maximum
C	0.1	0.15
Mn	1.17	1.55
Si	0.11	0.25
S	0.004	0.019
P	0.006	0.022
Al	0.01	0.09
Nb	0.033	0.087
Ti	0.01	0.07
V	0.025	0.081
Tf	780	915
Tb	500	730
YS	424	576
UTS	547	733

Since the measured values of YS and UTS show a wide range of scattering, the input parameters were normalized by pre-processing so that they fall in the interval [0, 1]. The result of the training procedure is shown in Figs. 6 (a and b). After the training procedure, the network was tested as shown in Fig. 6 (c and d). It can be concluded that the neural network predicted the actual YS and UTS, target, successfully.

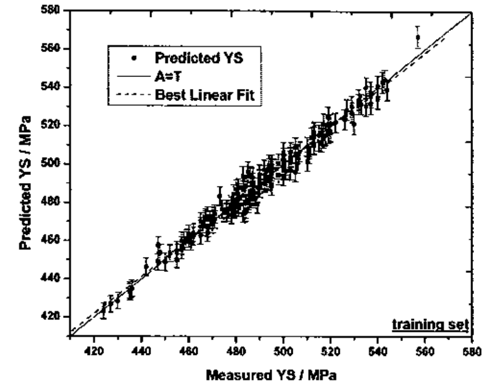


Fig. 6a. Predicted vs. measured yield strength (training set)

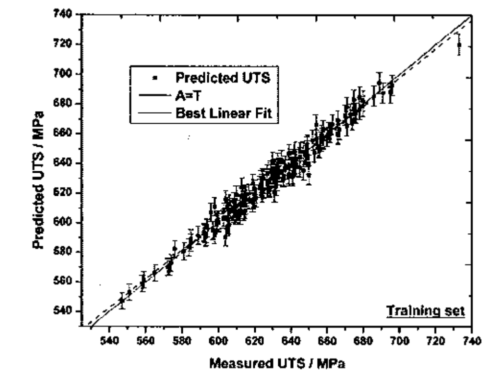


Fig. 6b. Predicted vs. measured ultimate tensile strength (training set)

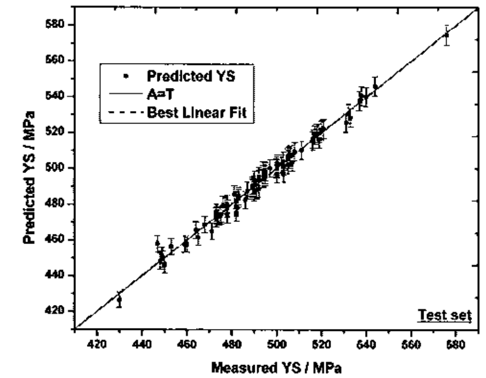


Fig. 6c. Predicted vs. measured yield strength (test set)

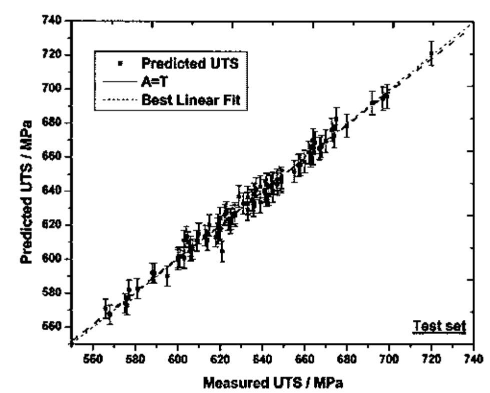


Fig. 6d. Predicted vs. measured ultimate tensile strength (test set)

In order to facilitate the comparisons between predicted values and experimental values, an error analysis has been done using the correlation coefficient mean relative error (MRE) criteria where x_i is the observed (experimental) value, y_i is the predicted value by the network and N is the number of data.

$$MRE(\%) = \frac{100}{N}\sum_{i=1}^{N}\left|\frac{x_i - y_i}{x_i}\right| \quad (5)$$

Using all data set the generalised regression neural network demonstrated pretty good approximation performance with correlation coefficient of R(YS,UTS)=(0.989, 0.987) and mean relative error of MRE (YS, UTS) = (5.38‰, 5.41‰), taking the nature of the specimens obtained by means of commercial steel production conditions. In other words, there is a good agreement between the experimental results and those predicted by the artificial neural network, see Fig. 7.

The significance is a measure of how much the inputs influence the output. Each variable was investigated for the best model, and presented in Fig. 8.

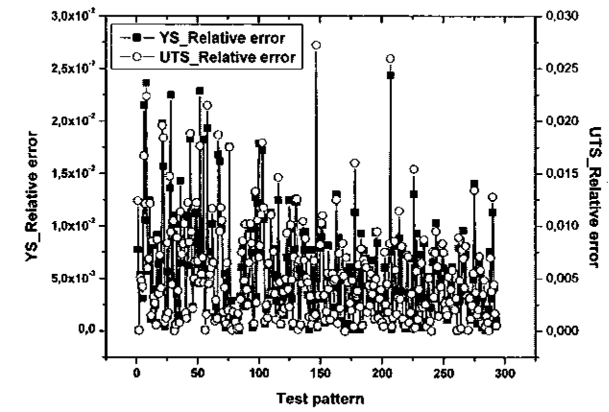


Fig. 7. Relative Error (RE) for YS and UTS (for all data set)

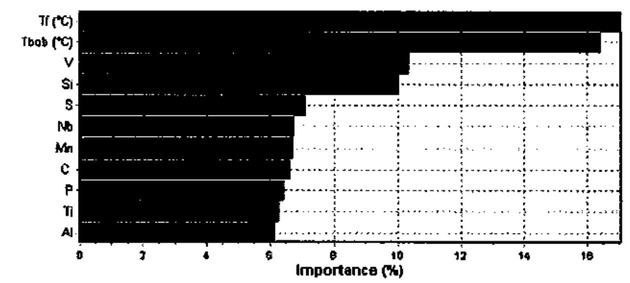


Fig. 8. Bar chart showing a measure of the model perceived significance of each input variables influencing the YS and UTS of the steel as deduced from the network

The temperature of finish rolling and of coiling, are seen to have a large influence on the output, which is consistent with metallurgical theory. However, each input was seen to offer at least a moderate contribution to the output. This therefore confirmed that they were a good choice of inputs. In summary, it was important to find out which variables are considered to be most significant, or those that contributed very little to the output. However, it is well understood that many of the variables have some bearing on steel strength. Overall, the aim was to obtain meaningful inputs that allow optimisation of mechanical properties within a predictive framework.

V. Application

Once the model was developed, its behaviour was compared to findings in the literature, using compositions in Table II. The aim was to show that it agrees with existing data of HSLA steels and has enough complexity to describe different relationships.

According to the results of the ANN, in the industrial hot rolling mill, the rolling and coiling temperature affects more the YS and UTS. To validate this, the TMCP is simulated in laboratory mill [41]. After cooling with water laminar cooling, the whole sequences of finish temperatures (800°C, 750°C and 700°C), as well as the different coil (annealing) temperatures (650°C, 600°C and 550°C) the predicted values of YS and UTS, are shows in Figs. 9a and 9b, respectively.

TABLE II
CHEMICAL COMPOSITION OF SAMPLE (IN % WEIGHT).

C	Si	Mn	P	S	Cr	Mo
0,139	0,130	1,51	0,011	0,004	0,01	0,01
Al	N	Cu	Nb	Ti	V	Ni
0,0243	0.0211	0,026	0,075	0,024	0,041	0,01

It would be interesting to find any non-linear relationships that are not captured by linear regression methods. This would show that the flexibility of neural networks may be more suitable for making predictions. To illustrate this, 3Dplots of YS were made for finish rolling temperature against coiling temperature, for optimizing the production of API X70 grade steel, Fig. 10a and the production of API X60 grade steel, Fig. 10b. "note that in Fig. 9, $Tf(1)=750°C$, $Tb(1)=500°C$ and for $I=2$ to 16: $Tf(I)=Tf(I-1)+7$and $Tb(I)=Tb(I-1)+10$".

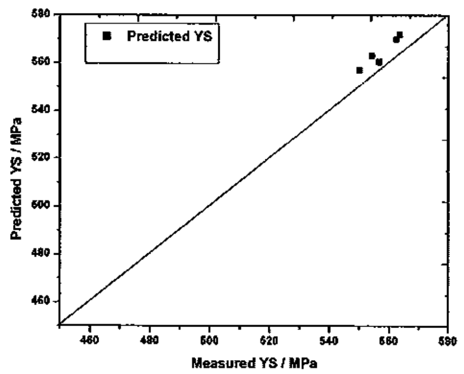


Fig. 9a. The predicted YS using composition in Table II

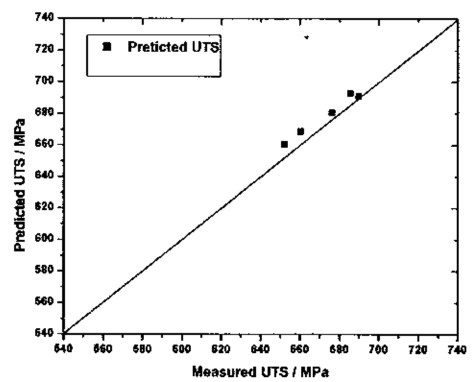
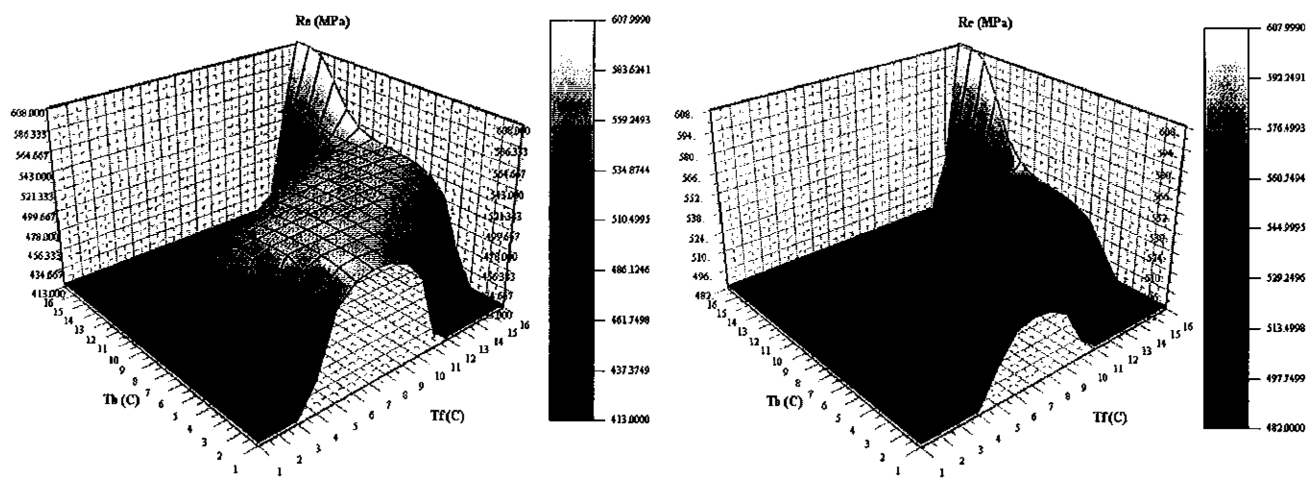


Fig. 9b. The predicted UTS using composition in Table II



(a) (b)

Fig. 10. The effect of finish rolling temperature against coiling temperature, on the YS using composition in Table II.
a) Production of API X70 and b) Production of API X60

VI. Conclusion

The best combinations of toughness and strength properties of microalloyed steels are very important for the applications of the steels in industry. Besides, the strength level of microalloyed steels is also important, however, it must be used only with sufficient level of toughness. On the other hand, the control mechanisms in industrial scale for both of the properties are very complex, because the many production parameters, which begin from the alloying and casting of the steel to the rolling and finishing, influence both of the properties during whole production steps.

In particular, keeping or obtaining a robust strength properties grade is possible only under rigid control of the whole production steps and parameters, such as chemical composition of steel, shape, composition and size of the non-metallic inclusions, temperature of whole production steps irrespective of casting, soaking or rolling. The systematical examinations of the rolling tests could not be achieved due to the slight changing of the parameters, such as chemical compositions or soaking temperature or time because of the commercial production nature of the processing conditions. Under these circumstances, the mechanical properties of the produced steels have been swayed in a relatively wide range, which are normally not acceptable in general use for the microalloyed steels.

As a conclusion, a generalised regression neural network model has been developed to predict the yield and tensile strengths level of the investigated microalloyed steel during the microalloyed steel production process. The presented prediction model demonstrated a good approximation performance between the experimental data and the neural network predicted output. Hence, the neural network based prediction model developed in this study can be used with a satisfactory degree of accuracy and reliability for determining the yield and tensile strengths in similar microalloyed steels.

Now that a feasible predictive model exists, it would be useful to find new compositions for microalloyed steels. Each input variable has some influence on the final steel strength. So to aid this investigation, a useful approach would be the use of "genetic algorithms". By using this technique in conjunction with neural networks, it is hoped that an efficient search of the envelope of all inputs can lead to the same or improved strength.

Acknowledgements

The authors would like to express their gratitude for the financial support by URASM CSC Annaba Center. Experiments on the industrial thermomechanical and tests were performed at the laboratory of Elhadjar Iron and Steel Factory and Freiberg University, which are gratefully acknowledged.

References

[1] Malcolm Gray J. *Technology of microalloyed steel for large diameter pipe.* Int J Pres Ves Pip 1974; 2:95–122.
[2] Sage AM. *Effect of rolling schedules on structure and properties of 0.45-percent vanadium weldable steel for x70 pipelines.* Met Technol 1981;8:94–102.
[3] Hart PHM, Mitchell PS. *The effect of vanadium on the toughness of welds in structural and pipeline steels.* Weld J 1995; 74:S239–48.
[4] Irvine KJ, Gladman T, Orr J, Pickerin FB. *Controlled rolling of structural steels.* J Iron Steel I 1970; 208:717.
[5] Matsubar H, Osuka T, Kozasu I, Tsukada K. *Investigation of metallurgical factors in production of high-strength steel plate with high toughness by controlled rolling.* Trans Iron Steel I Jpn 1972; 12:480.
[6] May MJ, Gladman T, Walker EF. *Recent developments in ultra high strength steels and their applications.* PhilosTransRoyal Soc, London Series 1976; 282:377.
[7] Brownrigg A, Boelen R. *Yielding behavior of some Mn–Mo–Nb pipeline steels.* Met Forum 1981;4:245–52.
[8] Shimizu H, Gibbon WM. *Evaluating the dynamic toughness properties of pipeline steels.* Can Metall Quart 1982; 21:103–9.
[9] Pluvinage G, Krasowsky AJ, Krassiko VW. *Influence of mechanical and metallurgical parameters on dynamic fracture-toughness of 2 pipeline steels.* Mem Etud Sci Rev Met 1992;89:137–52.
[10] Iung T, Difant M, Pineau A. *Resistance and toughness of pipeline steels crack-arrest in cleavage fracture.*Rev Metall Cahiers Informations Tech 1995; 92:227–39.
[11] Schofiel R, Weiner RT. *Simulating HAZ toughness in pipeline steels.* Met Constr Br Weld J 1974; 6:45–7.
[12] Croft NH, Deardo AJ, Gray JM. *The effects of filler metal composition, heat input and post-weld heat-treatment on the properties of submerged-arc welds in X70 grade linepipe steel.* J Met 1982; 35:A64.
[13] Hulka K, Peters P, Heisterkamp F. *Trends in the development of large-diameter pipe steels.* Steel Transl 1997; 27:64–70.
[14] Hulka K, Heisterkamp F. *Development trends in HSLA steels for welded constructions.* Mater Sci Forum 1998; 284:343–50.
[15] Heisterkamp F, Hulka K. *Low-carbon Mn–Ni–Nb steel. 2. Weldability.*Met Technol 1984; 11:545–9.
[16] Mujahid M, Lis AK, Garcia CI, De Ardo AJ. *HSLA-100 steels: influence of aging heat treatment on microstructure and properties.* J Mater Eng Perform 1998; 7:247–57.
[17] Zhao MC, Yang K, Shan YY. *The effects of thermo-mechanical control process on microstructures and mechanical properties of a commercial pipeline steel.* Mater Sci Eng a 2002; 335:14–20.
[18] Zhao MC, Yang K, Shan YY. *Comparison on strength and toughness behaviors of microalloyed pipeline steels with acicular ferrite and ultrafine ferrite.* Mater Lett 2003; 57:1496–500.
[19] Zhao MC, Tang B, Shan YY, Yang K. *Role of microstructure on sulfide stress cracking of oil and gas pipeline steels.* Metal Mater Trans A 2003; 34A:1089–96.
[20] DeArdo AJ. *New challenges in the Thermomechanical processing of HSLA steels.* Mater Sci Forum 2003;426–432:49–56.
[21] Bleck W, Frehn A, Kechagias E, Ohlert J, Hulka K. *Control of microstructure in TRIP steels by niobium.* Mater Sci Forum 2003; 426:43–8.
[22] Kneissl AC, Baldinger P. *Structure and properties of TM processed HSLA steels.* J de Phys 1993; IV 3:77–82.
[23] Wang Shyi-Chin, Hsieh Rong-Iuan, Liou Horng-Yih, Yang Jer-Ren. *The effects of rolling processes on the microstructure and mechanical properties of ultra low carbon bainitic steels.* Mater Sci Eng 1992; 157A:29W–36W.
[24] M. C, H.M. Ertunc,, M. Yılmaz. *An artificial neural network model for toughness properties in microalloyed steel in consideration of industrial production conditions.* Materials and Design 28 (2007) 488–495
[25] S. Datta, M.K. Banerjee : Mapping the input–output relationship in HSLA steels through expert neural network, Materials Science and Engineering A 420 (2006) 254–264

[26] N.K. Bose, P. Liang, *Neural Network Fundamentals*, McGraw-Hill Inc.,1996.
[27] S. Datta, J. Sil, M.K. Banerjee, ISIJ Int. 39 (1999) 986–990.
[28] S. Datta, M.K. Banerjee, ISIJ Int. 44 (2004) 846–851.
[29] S. Datta, M.K. Banerjee, Scand. J. Metall. 33 (2004) 310–315.
[30] S. Datta, M.K. Banerjee, ISIJ Int. 45 (2005) 121–126.
[31] Haque ME, Sudhakar KV. *ANN back propagation prediction model for fracture toughness in micro alloy steel.* Int J Fatique 2002;24: 1003 – 10.
[32] H. K. D. H. Bhadeshia: *Neural Networks in Materials Science*, ISI International 39:10 (1999), pp. 966-979.
[33] Bhadeshia HKDH. ISIJ Int 1999: 39: 966.
[34] Rumelhart DE, Hinton GE,Williams RJ. Nature 1986: 323: 533.
[35] Fletcher R, Reeves CM. Comput J 1964: 7: 149.
[36] Polak E, Ribiere G. Rev Fr Inform Rech Oper 1969: 16-R1: 35.
[37] Moller MF. Neural Netw 1989: 2: 357.
[38] Dennis JE, Schnabel RB. *Num methods for unconstrained optimization and nonlinear equations,* Prentice-Hall, Englewood Cliffs, NJ, 1983.
[39] Riedmiller M, Braun H. Proc IEEE Int Conf Neural Netw 1993: 49.
[40] Hagan MT, Menhaj M. IEEE Trans Neural Netw 1994: 5: 989.
[41] A.Guedri et al: *Effect of different rolling schedules on the mechanical properties and microstructure of C Mn (V-Nb-Ti) pipeline steel,* (I.RE.M.E.), 1, 4 (2007) 397-405.

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International Review of Mechanical Engineering (I.RE.M.E.), Vol. 1, n. 6
November 2007

Stress Triaxiality as Fracture Toughness Transferability Parameter for Notched Specimens

O. Akourri[1], I. Elayachi[1], G. Pluvinage[2]

Abstract – *The problem of fracture toughness transferability is treated by using the stress triaxiality and by introduction of a new transferability parameter called p. This parameter is a combination of effective critical stress triaxiality (mean value of stress triaxiality over effective distance) and multiplies by a geometrical function. Application of this method has been made on three point bending specimens made in XC 38 steel. Comparison of 2D and 3D approaches is made.* ***Copyright © 2007 Praise Worthy Prize S.r.l. - All rights reserved.***

***Keywords**: Transferability parameter, Stress triaxiality, Notch radius, Notch depth, Steel*

Nomenclature

a	notch or crack length,
K_ρ	notch stress intensity factor,
p	transferability parameter,
r	distance,
W	specimen width,
X_{ef}	effective distance,
α	notch sensitivity,
β	stress triaxiality,
σ_{ef}	effective stress,
σ_h	hydrostatic stress,
$\sigma_{eq,VM}$	equivalent Von Mises stress,
σ_i	principal stresses (i=1,2,3),
$\sigma_{yy}(r)$	maximum principal stress (opening stress),
ρ	notch radius,
$\chi(r)$	relative stress gradient.

I. Introduction

Transferability of mechanical properties means that these properties measured in some conditions of geometry, loading mode, constraint etc… have to be modified to be applied in other similar conditions. The mechanical properties measured in reference conditions are naturally the reference properties. This means fundamentally, that the mechanical properties are not intrinsic to material, which is a seldom assumption used in structure design. However, this problem is known since a long time and Galileo Galilei have say during the 17th century "It is not so simple to go from the small to the big". Several theories are used to examine this problem, constrain plasticity, fractal theory, probabilistic approach, dimensional equations etc…

Transferability of fracture toughness is an important problem for structural design because change of geometrical or constraint conditions may promote brittle fracture. Fracture toughness transferability (FTT) is made by the way of a transferability function *t(p)* which depends of transferability parameter p. If R is the fracture toughness in given conditions and R_{ref}, the fracture toughness in reference conditions, transferability function is defined as:

$$R = R_{ref}\,t(p) \qquad (1)$$

p is a transferability parameter chosen according to different approaches.

The choice of a transferability parameter remains an open question when we study the transferability with simultaneously two or several parameters.

It is well known that ductile fracture is sensitive to stress triaxiality. In the literature, one finds several indicators to quantify the state of the constraints at defect tip. Over the list of these indicators, one can quote the constraint T [1], the Q parameter [2] and the multiaxiality parameter q [3]. In this work, β is used as a measure of stress triaxiality. This parameter is defined as the ratio of the hydrostatic stress over the equivalent Von Mises stress:

$$\beta = \frac{\sigma_h}{\sigma_{eq,VM}} \qquad (2)$$

where:

$$\sigma_h = \frac{\sigma_{xx} + \sigma_{yy} + \sigma_{zz}}{3}$$

and:

(continued from outside front cover)

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