THE USE OF NIOBIUM BEARING FERRO-ALLOYS IN THE MANUFACTURE OF STRUCTURAL STEELS IN THE USSR

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Summary

Information is presented concerning the use of niobium as a microalloying element in constructional steels of various types. Niobium causes substantial refinement of grain size and inhibits the process of static recrystallization. It is, therefore, widely used in high strength low-alloy steels subjected to controlled-rolling or thermo-mechanical treatment. The largest strength increases are observed with a niobium content of up to 0.05 percent at which point the impact toughness diminishes slightly. Increased amounts of niobium favorably affect both the impact toughness and the transition temperature.

The effectiveness of niobium usage in existing types of construction steels, including HSLA steels intended for the manufacture of weldable large-diameter linepipe for use in Arctic environments is described.

The Practice of Using Niobium in the Production of Structural Steels

Research laboratory and pilot-scale investigation concerning the use of niobium are widely conducted in the Soviet Union with the aim of developing new grades of structural steels having higher strength and toughness. The steels are utilized to solve new engineering problems and allow efficient designs which result in enhanced economy, reliability and durability of construction.

The use of niobium in low-alloy constructional steels is based on the favorable influence of dispersed particles on microstructural formation processes and related mechanical properties. The solubility of niobium in austenite and the precipitation of particles in austenite or ferrite define the extent of hardening by dispersion hardening, grain refinement and the increase in dislocation density.

The addition of niobium to low-pearlitic C-Mn steel contributes to the refinement of austenitic, and ferritic grains, see Figure 1 and Figure 2 respectively and lowers the sensitivity of austenitic grain to coarsening during heating. The finer original austenitic grain has a favorable influence on the mechanical properties of both low-alloy constructional steels and high-strength weldable steels having either bainitic or martensitic structure. In the latter cases, the dispersion of the final structure is greatly influenced by the size of the original austenitic grains.

Niobium has a favorable and marked influence on the static recrystallization processes of austenite after hot deformation. An increase in the niobium content in low-pearlitic steel Grade 09G2 from 0 to 0.08 percent will lead to displacement of softening curves to greater holding times, Figure 3, which reflects the inhibition of static recrystallization. Microalloying with niobium contributes to an increase in the time prior to the beginning of static recrystallization, thus favoring strain accumulation in each succeeding pass. Such strain accumulation has a favorable influence on the formation of refined ferritic grains during they → a transformation process. Analysis of the softening curves of hot deformed austenite of steel type 09G2, having different niobium contents, showed that the action of niobium on inhibition of static recrystallization increases with decrease in the deformation temperature as characterized by the increase in the slope of the T_{50} curve (time for achieving 50% softening) relative to the x-axis, Figure 4.

Niobium's hardening influence is attributed to the precipitation of fine dispersed carbonitride phase Nb(CN) in the ferrite during cooling. Thus, the magnitude of dispersion hardening from the niobium carbonitride phase increases when more of the niobium is dissolved in the austenite solid solution prior to rolling and when it stays there until transformation occurs. Figure 5 shows that for steel type 08G2FB, after quenched from 1000 C, 800 C and 720 C (without deformation), the amount of chemically determinable Nb (CN) + V (CN) carbonitride phase is not large. Thus, hot plastic deformation at these temperatures stimulates the dispersion of Nb (CN) and V (CN) particles in the austenite. Very favorable temperature-strain conditions for the carbonitride-phase precipitation are established in the temperature range of 850 C.

The favorable effect of niobium on austenite grain size, the inhibition of recrystallization processes, and the intensification of carbonitride precipitation during plastic deformation result in steels responsive to controlled rolling and capable of developing an attractive combination of high mechanical properties.

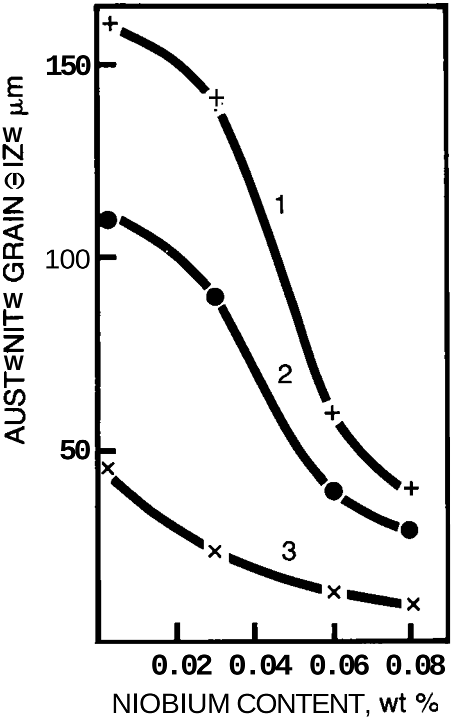

Figure 1. Influence of niobium on the austenite grain size in low pearlitic C-Mn steel. Heating temperature: 1 - 1150 C, 2 - 1100 C, 3 - 1050 C.

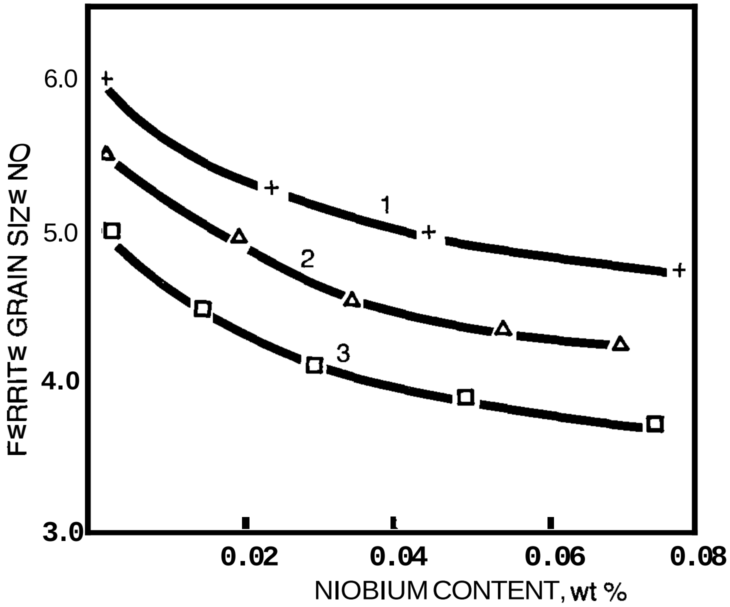

Figure 2. Influence of niobium on ferrite grain size of low-pearlitic steels after controlled rolling. 1 - C-Mn steel, 2 - C-Mn-V steel, 3 - C-Mn-Ti steel.

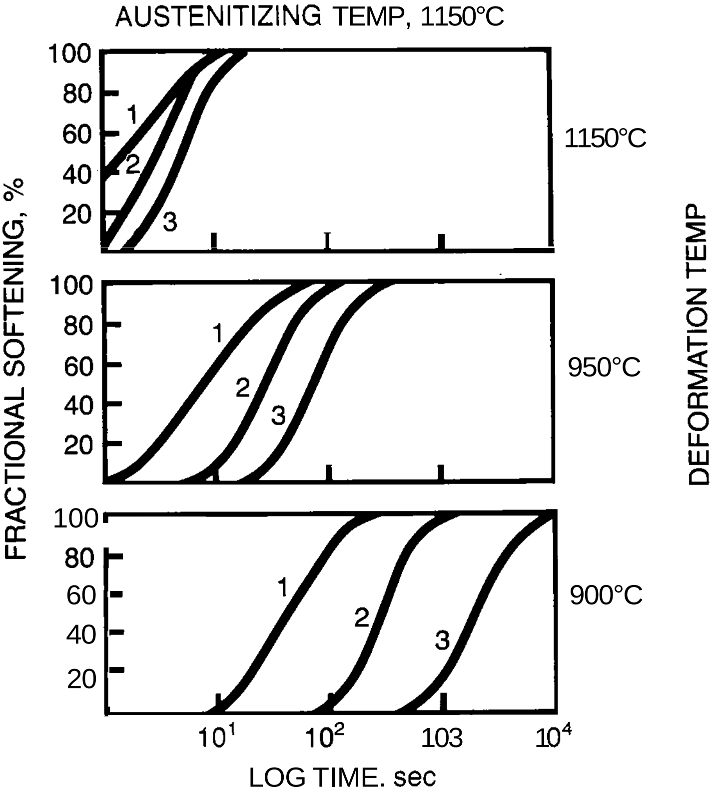

Figure 3. Niobium influence on austenite static recrystallization after hot rolling.
1 - 0% Nb, 2 - 0.038% Nb; 3 - 0.08% Nb.

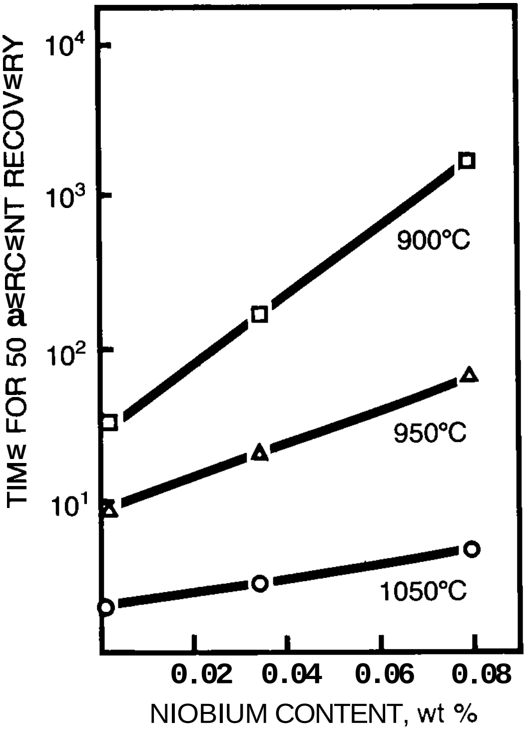

Figure 4. The influence of niobium content in low-pearlitic C-Mn steel on the holding time necessary for achieving 50% softening (T_{50}). Deformation temperatures: 1 - 900 C, 2 - 950 C, 3 - 1050 C. Austenitization temperature - 1150 C.

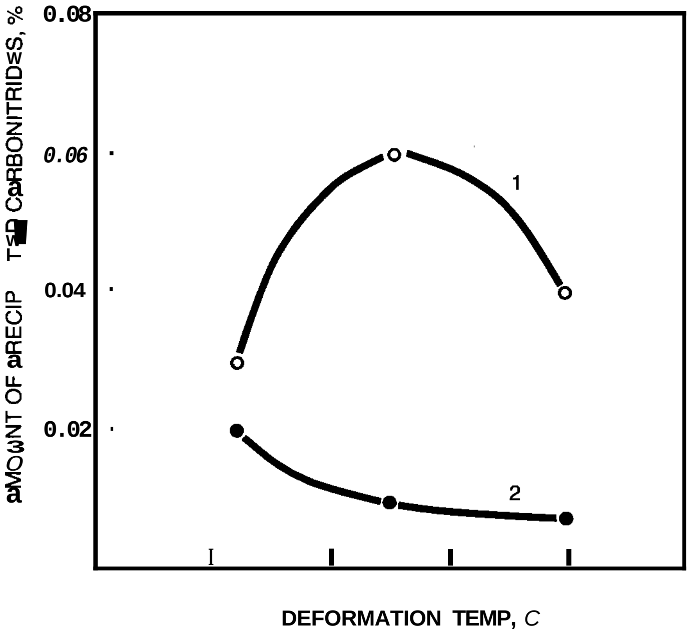

Figure 5. Influence of deformation on the amount of precipitated carbonitride phase Nb(CN) + V(CN) in steel type 09G2FB.

1 - with deformation

2 - without deformation

Microalloying low-pearlitic steels with niobium enables one to considerably raise their strength levels. For example, increasing the niobium content from 0 to 0.10 percent in steel grades 09G2F and 09G2T ensures an increase in strength of 65 MPa, Figure 6. The highest hardening rate is observed up to *0.04* - 0.05 percent niobium. Further increases result in little or no additional strengthening, although the toughness may improve. This is due to the fact that at the austenitizing temperature of 1115 C (the reheating temperature in this study) only about *0.04* - 0.05 percent niobium can dissolve in the austenite. Precisely this amount of niobium in precipitating from the ferrite solid solution as dispersed Nb (CN) particles thereby contributing to the intensive rise in strength. At a niobium content higher than its solubility limit at a given temperature, it will form quite large particles which have no additional contibution to hardening. In spite of the considerable increase in the strength, the plasticity of both steels remains at a sufficiently high level, Figure 6b.

Microalloying of low-pearlitic steels with niobium has an ambiguous influence on the impact strength and contributes to the lowering of the brittle transition temperature T_{50}, Figure 7a and 7c, defined by the presence of 50 percent shear area in the fracture of Charpy V-notch specimens. Increasing the niobium content to 0.10 percent leads to an increase in the amount of the ductile constituent (shear area) in the ductile-brittle temperature range, Figure 7b, thereby indicating an increase in the steel's resistance to brittle failure. Increasing niobium concentration from 0.0 to 0.05 percent causes a slight reduction in impact strength (Charpy shelf energy), but at higher niobium contents, an increase in impact strength compensates for the initial reduction of Charpy energy resulting from the deleterious influence of dispersion hardening.

The influence of niobium on weldability was investigated by analyzing austenite phase transformation kinetics of weld-heat affected zones, Figure *8.* Niobium increases austenite stability in steels with 0.1 percent carbon and the optimum benefit was found at 0.05 percent. It was noted that in the diffusion-transformation region, there is a decrease in polygonal ferrite content accompanied by a lowering of the ferrite and pearlite start temperature. The martensitic region in the diagram is shifted to slower cooling rates and lower temperatures. At a niobium level of 0.15 percent, the effect in increasing austenite stability weakens. Mechanical property evaluation of weld-heat affected zone (HAZ) of niobium-bearing steels revealed that niobium increases the strength over the whole range of structures investigated.

Maximum impact strength of the weld-heat affected zone was found in the region of the pearlite-bainite transformation of austenite. The Charpy values at a niobium content of 0.05 percent are 30 percent higher than in the weld-affected zone of a steel of similar composition, but without niobium. Increasing the niobium content from 0.05 percent up to *0.14* percent, results in a gradual decrease in impact strength. Practically, for the fulfillment of the requirements relative to a balanced group of properties of the base metal, and considering controlled rolling, niobium, vanadium, molybdenum and other alloying elements are usually used at the same time.

Niobium has a favorable influence on the weldability of low-alloyed steels. The maximum effect of its action is attained with the formation in the HAZ of a bainite-pearlite structure having a "rack-type" morphology.

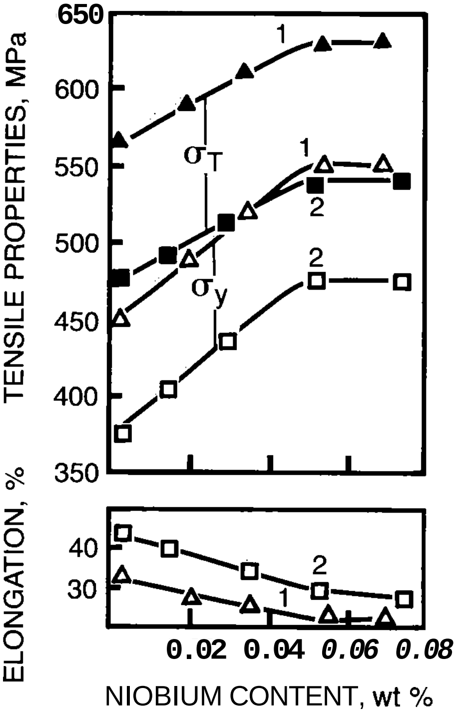

Figure 6. Influence of niobium on the mechanical properties of low-pearlite steels after controlled rolling.

1 - steel 09G2F + Nb

2 - steel 09G2T + Nb

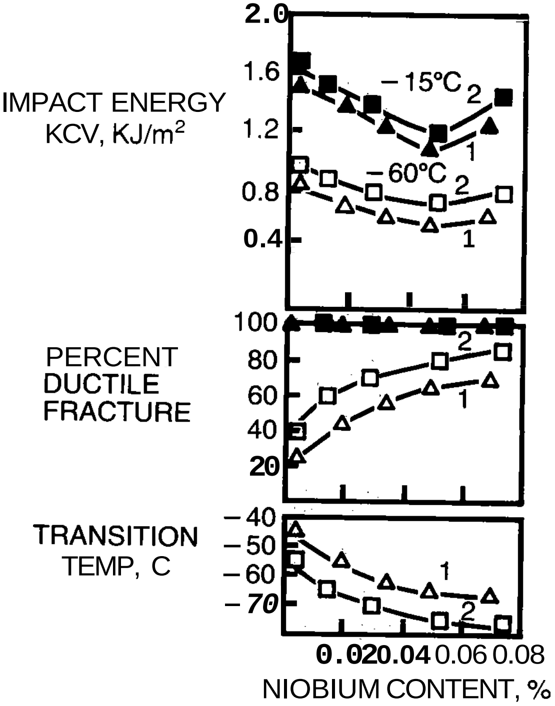

Figure 7. Influence of niobium on impact strength fibrous constituent and brittle transition temperature of steels 09G2F (1) and 09G2T (2) after controlled rolling.

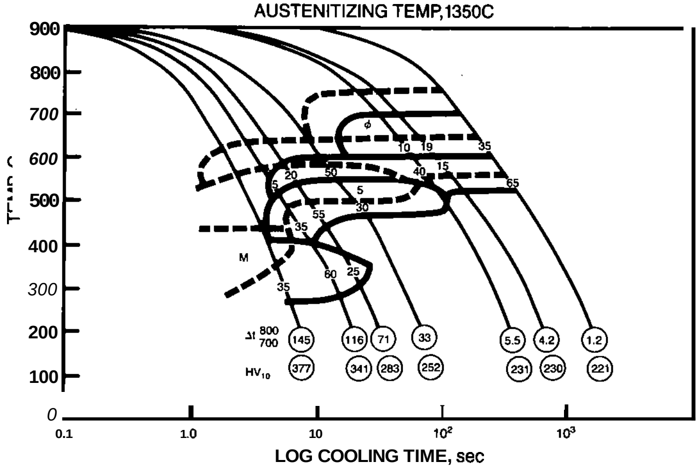

Figure 8. Influence of niobium on the kinetics of austenite phase transformation in the weld-heat affected zone of controlled rolled steel.

Key - Solid line steel 09G2B
Dashed line steel 09G2

Considerable progress has been achieved in the last few years in the development of coiled-strip (multi-layered) pressure vessels of unique designs which are used in the chemical industry in connection with mineral fertilizers production. The replacement of traditional vessels utilizing all-forged shells by coiled-strip vessels has simplified production technology and considerably boosted operational reliability.

A high-strength coiled steel designated 08G2CFB containing 0.01 - 0.04 percent niobium and having a strength of 590 MPa, develops high levels of ductility without heat-treatment, and has been adopted to enhance the operational properties of vessels operating at a pressure of 300 atm and a temperature of 300 C.

Due to the low carbon equivalent (<0.43%) and strengthening by niobium, the coiled steel type 08G2CFB has good weldability despite the high strength level; this is very important for the reliability of pressure vessels. The steel is also characterized by fine grain size ASTM #10 - 11, and freedom from non-metallic inclusions. Contemporary production processes are applied in making the coiled steel type 08G2CGB comprising melting in basic oxygen furnace followed by ladle treatment with synthetic slags. Rolling is carried out on continuous 2000 mm mills using controlled rolling schedules which ensures a combination of excellent mechanical properties as detailed in Table I below:

Table I. Mechanical Properties of Steel Grade 08G2CGB

Test Temperature	T.S. MPa	Y.S. MPa	El_5 percent	Impact Strength KCU MJ/m^2 at -40 C
+ 20	620-660	490-600	22–25	0.1 - 0.15
300	540-580	370-450	18–23	

The impact strength measured on KCU specimens maintains a high value down to –100 C combined with a satisfactory fracture appearance transition temperature, Figure 9.

For the production of 1420 mm diameter pipes for a service pressure of 7.5 MPa, a similar low-pearlite steel (09G2FB) has been developed containing 0.02 - 0.04 percent of niobium that is suppled in the controlled rolled condition. The niobium carbonitride which precipitates from the solid solution in the form of finely dispersed particles, inhibits the growth of austenite grain during re-heating and contributes to grain refinement during controlled rolling. Niobium strengthens the steel as a result of such grain refinement in combination with the usual dispersion hardening. For achieving the required impact strength value (>0.9 w m^2 at -15 c KCV) it is necessay to carry out extreme desulphurization of the steel to a sulphur content of <0.006 percent, and to combine it with additional inclusion modification by treatment with calcium or rare earth metals. After such a treatment, the manganese sulphides develop a globular form which is not detrimental to the impact strength.

The main purpose of controlled rolling is to obtain a fine-grained structure that ensures a proper ratio of strength, placticity and ductility, particularly brittle fracture resistance measured using through-thickness DWTT specimens (>85% fibrous fracture at -15 C).

Proper selection of the basic composition of steel grade 09G2FB containing niobium and the related technology for sheet production enable one to make a structural material having attractive combinations of mechanical properties; strength, toughness and brittle fracture resistance, as illustrated in Figure 10. Typical properties are Y.S. > 460 MPa, T.S. > 560 MPa, El_5 > 22 percent, KCV at 15 C > 0.9 MJ/m^2 and KCU at -60 C > 0.6 MJ/m^2, with the shear area (FATT) in DWTT specimens being not less than 85 percent at -15 C at a carbon euivalent of <0.43.

Results concerning the kinetics of austenite transformation and impact strength variations in the weld-heat-affected zone of low-pearlitic vanadium-niobium steel grade 09G2FB, showed that a considerable increase in toughness arises when the cooling rate is increased above 8 C/s, reaching a maximum value in the range 20 - 60 C/s, (Figure 11). Comparative analysis of the microstructures showed that niobium in the presence of vanadium contributes to an increase in the dispersion of intermediate transformation products having a "rack-like'' morphology. Such HAZ structures exhibit the best toughness at low temperatures.

The practices utilized show good compatibility of the steels with pipe production techniques and with the procedures used when laying gas pipelines. Special investigation of 1420 mm grade 09G2FB pipes for a working pressure of 7.5 MPa indicated high reliability and serviceability of the pipes with the steel retaining high impact strength at low temperatures, Figure 12.

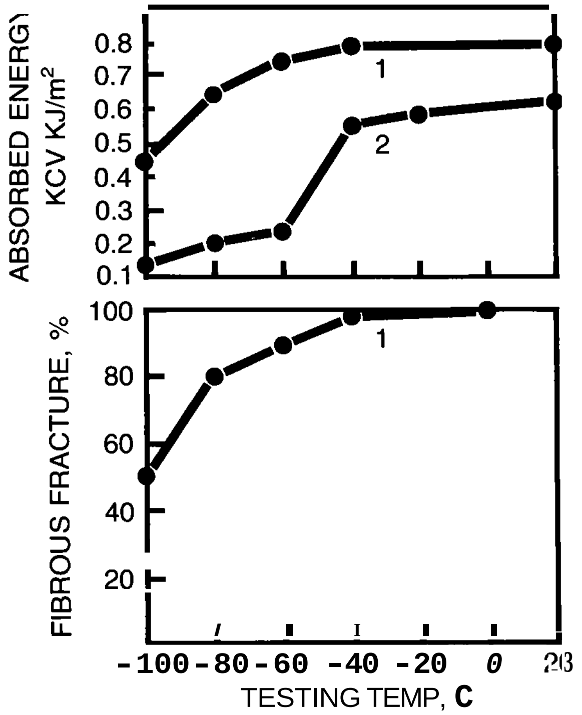

Figure 9. The influence of test temperature on impact strength and fibrous constituent into the fracture for steel 08G25FP.

1 - notch 1 mm in diameter
2 - notch 0.25 mm in diameter

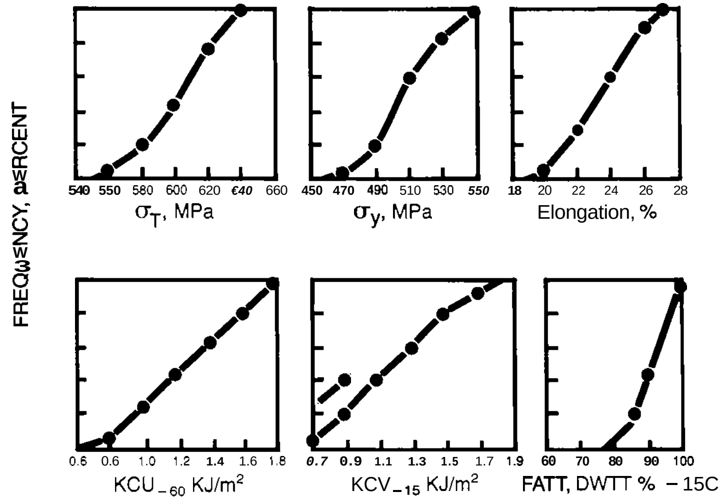

Figure 10. Frequency curves of mechanical properties of sheets from controlled rolled steel 09G2FB.

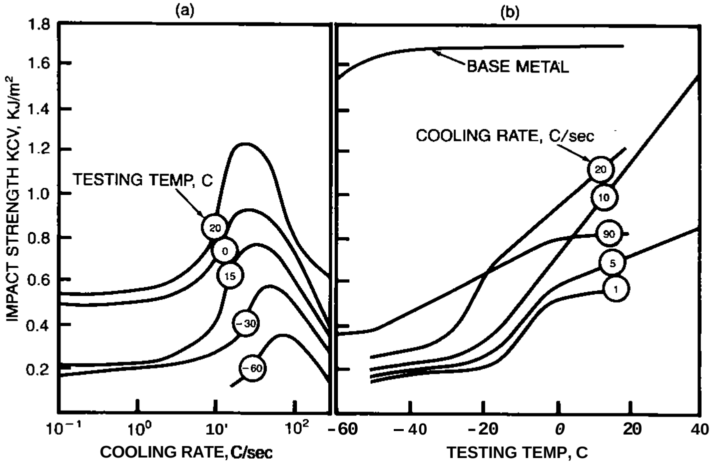

Figure 11. The influence of cooling rate (a) and test temperature (b) on the impact strength of weld-heat affected zone in steel 09G2FB.

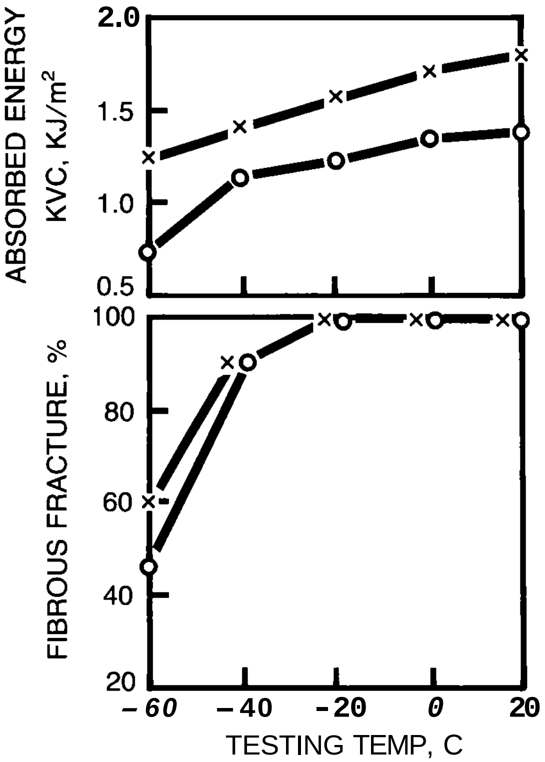

Figure 12. The influence of test temperature on the impact strength of steel 09G2FB.

The absorbed energy in DWTT specimens tested at -15 C ranges between 4 and 5 kJ. The base metal has a high resistance to crack initiation at temperatures down to -60 C. The brittle transition temperature determined in pheumatic tests lies below -15 C, whilst the low crack propagation rates (138 - 223 m/s) indicates a high resistance of the pipes to propagating ductile fracture. Pipes 1420 mm. in diameter made from grade 09G2FB steel, have been extensively and successfully used in severe regions in the extreme north of the USSR in gas pipelines at a working pressure of 7.5 MPa. Economically-alloyed brittle fracture resistant steel, grade 06G2NAB, containing 0.14 percent niobium, has been developed for structures to be operating at low temperatures. Sheets from this type of steel after normalizing have a ferrite grain size of ASTM 12, with a pearlite content of <5 percent. The steel has a high strength level and hardening rate when tested in the temperature range between +20 C to -196 C, equal to 13 MPa increase for each 10 C decrease in the test temperature. It was also noted that steel grade 06G2NAB retains high placticity at the lowest temperatures investigated (-200 C), Figure 13.

The addition of 0.02 - 0.04 percent niobium to a high strength bainitic steel grade 14X2GMR, produces an as-rolled fine-grain structure (ASTM No. 9 - 10 compared with ASTM No. 6 - 7 in the same steel without niobium) as a result of the formation of carbonitride phases Nb (CN) which inhibit both austenite grain growth and static recrystallization after completion of rolling. Achievement of a more dispersed microstructure in steel grade

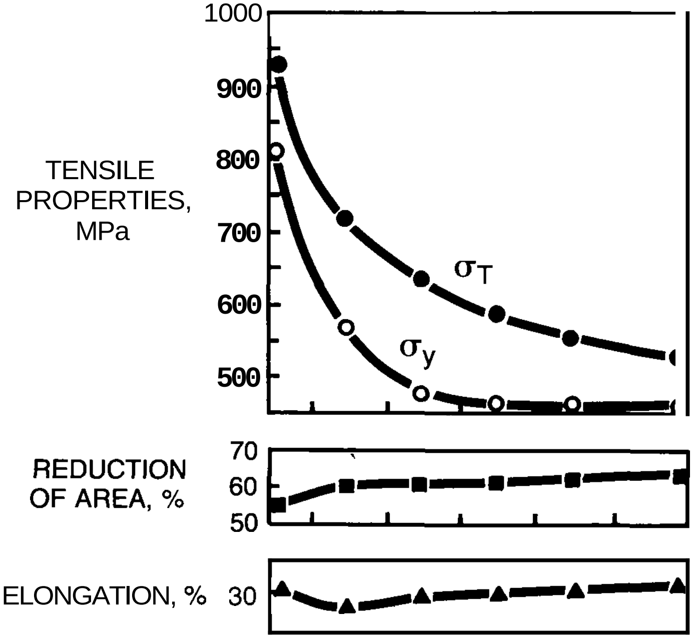

Figure 13. Mechanical properties of steel
06G2HAB at low temperatures.

14X2GMRb produces a higher impact-strength compared to steel grade 14X2GMR, Figure 14. It has been shown that the thicker the as-rolled products, the more intense is the influence of niobium on the impact strength. It should be noted that the increase in impact strength is accompanied by a yield strength increase averaging 100 MPa.

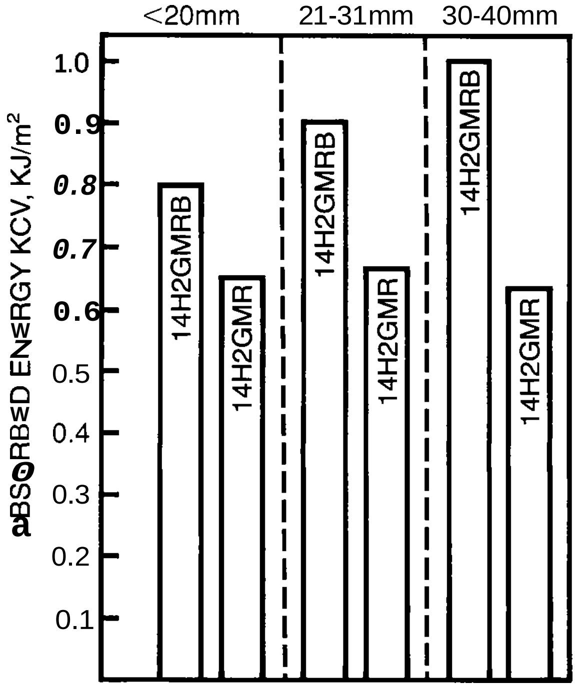

Figure 14. The impact strength of. high-strength C-Cr-Mn heat treated steels containing niobium.

Conclusion

Niobium as a microalloying element is widely used in metallurgical practices and procedures for the production of structural steels used for many different purposes. The steels may'be used in the hot-rolled, normalized and heat-treated conditions. The addition of small quantities of niobium improves the steel by enhancing strength and ductility and improving processing characteristics.

References

1. N. P. Lyakishev, S. A. Golovanenko, U. I. Matrosov, et al, New Low-Pearlite Steel 09G2FB For Pipes of 1420 mm. Diameter, Stal, 4, (1980) pp. 327-330.