THE STATE OF THE ART OF CHINESE PIPELINE PROJECTS AND BASIC RESEARCH OF AUSTENITE PROCESSING OF NB-BEARING PIPELINE STEELS*

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Abstract
Aiming at greatly increasing efficiency and saving budget, higher strength and larger-diameter pipes have been developed and applied for constructing long distance pipeline projects in China. At the same time, in order to produce pipeline steel with high strength, high toughness and excellent DWTT performances, it is critical to refine austenite grain by static recrystallization rolling. Therefore, this paper focuses on the brief introduction of development of pipeline projects in China and also on the basics research in the field of static recrystallization during austenite processing of Nb-bearing steel.
Keywords: pipeline steel, Nb-bearing, recrystallization, stress relaxation test.

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** Technical contribution to the 11th International Rolling Conference, part of the ABM Week 2019, October 1st-3rd, 2019, São Paulo, SP, Brazil.*

1 Introduction of long distance pipeline projects in China

With the urgent demand of clean energy for economy growth and reduction of air pollution, more and more pipeline projects had been completed and have been launching in the past decades. Long distance pipeline is the best choice to transmit natural gas with the benefit of low cost and high efficiency. Actually, there are three phases of the development of pipeline in China. In 1970's, short distance oil pipelines were built by using TS52K (API X52) supplied by Japanese steel company. However, after reforming and opening policy started since 1978, the industria-lization promote the energy consumption in economy developing areas, such as south and east coast cities. In 1990's, X52-X70 grade pipeline steels were developed successfully by Chinese steel company, and gradually got widely used to build short distance pipeline. From 2000, it is come to the third phase, new era of pipeline in China, the long distance gas pipeline projects developing rapidly. The first and second west to east natural gas pipeline were built and completed in succession.

The highlights of Chinese pipeline projects are listed in Table1[1-3]. The characteristics of five long distance pipeline projects in China are demonstrated, they reflect the level of long distance pipelines in China. The construction of 1st West-East Gas Pipeline (WEGP) was launched on July 4th, 2002, completed and used to transport gas on December 31st, 2004. It is the first long distance natural gas pipeline designed and build by China National Petroleum Corporation (CNPC), the annual gas output is 17 bm^3, and it transmits natural gas from Tarim Basin, Xinjiang province to Henan province, Anhui province, Zhejiang province and Shanghai city. The length of this pipeline is about 4200 km, the scale of investment reaches 140 billion RMB, the steel grade is X70, the wall thickness is 14.6mm, the diameter of pipe is 1016 mm, and the design pressure is 10 MPa.

Table 1. Highlights of long distance gas pipeline projects in China

Project	1st WEGP	2nd WEGP	3rd WEGP	R-C EGP	XYZ CGP
Construction period	2002-2004	2008-2012	2012	2017-2019	2017-
Steel grade/API	X70	X80	X80	X80	X80
Diameter of pipe/mm	1016	1219	1219	1422	1219
Maximum pressure/Pa	10	12	12	12	12
Wall thickness of spiral pipe/mm	14.7	18.4	18.4	22	18.4
Wall thickness of longitudinal pipe/mm	18.4	22.4	22.4	26	22.4
Total length/km	4200	7000	7378	3170	8280
Annual transmission capacity/bm3	15	30	30	38	30
Investment /billio RMB	140	142	120	-	159

The 2nd WEGP started to build on February 22nd, 2008, it was completed and put into operation on December 30th, 2012. The annual gas transportation capacity is 30 bm^3. The total length of this project is more than 7000 km from Horgos, Xinjiang to Guangzhou, Guangdong and Shanghai. The total investment is 142.2 billion RMB. The pipeline steel grade is X80 [4], the diameter is 1219 mm, and the design pressure is 10-12MPa.

The 3rd WEGP started to construct on October 17th, 2012, it is under constructing and will be put into operation soon. The annual gas transmission capacity is 30 bm^3. The 3rd WEGP includes a truck line, eight branch lines, the total length is about 7378 km, from Horgos，Xinjiang port to Fuzhou, Fujian province, the total investment is about 120 billion RMB, the pipeline steel grade is X80, the diameter is 1016~1219 mm, and the pipe design pressure is 10~12 MPa.

Russia to China east gas pipeline (R-CEGP) starts form Heihe, Heilongjiang to Shanghai. The length of new construction line is 3170 km. In the common witness of the two heads of the states, CNPC and the Russian gas company signed the China-Russian natural gas purchase and sale contract on May 21st, 2014, the contract period is 30 years. This pipeline project will be built by X80, the diameter is 1422 mm, and the pressure is 12MPa.

In October 2015, the National Development and Reform Commission formally approved the Xinyuezhe coal gas pipeline (XYZCGP). This pipeline project includes a main line, five branch lines, starting from Yining, Xinjiang to the Shaoguan, Guangdong Province, the total length is 8280 km, the annual gas transmission capacity is 30 bm^3, and the total investment is 159 billion RMB. Pipeline steel X80 is used for this project, the diameter is 1219 mm and the design pressure is 12 MPa.

2 Basic research of austenite processing of Nb-bearing steel

It is most significant to use Nb as a microalloy element during TMCP to control static recrystallization and refine the prior austenite grain size [5-7]. Higher Nb concept has been applied in microalloying design of pipeline steel for strengthening and toughening the plat and strip of X70 and X80 [8-10]. However, an in-depth under-standing of the Nb content and rolling process parameters on static recrystal-lization will play an important role in guiding the implementation of the control rolling process.

Effect of Nb content on static recrystallization

Three low carbon steels were used for stress relaxation tests, as shown in Table 2, therein, s1, s2 and s3 were laboratory steels with different Nb contents ranging from 0.012wt%to 0.10wt%, which were used to investigate the effect of niobium on recrystallization and precipitation behavior. Figure 1 presents the process for the stress relaxation tests. It shows that after 25% reduction at a 1s-1 strain rate at different temperatures, the specimens were held for 400s at constant strain, and the stress-time curves were recorded. Actually, the stress relaxation method [11] can supply enough data to analyze the whole softening behavior as discrete events and can be recrystallization behaviors, solute dragging

Table 2. Chemical Compositions of Experimental Steels

	C	Mn	Nb	N(ppm)
s1	0.04	1.71	0.012	≤40
s2	0.04	1.76	0.063	≤40
s3	0.04	1.72	0.10	≤40

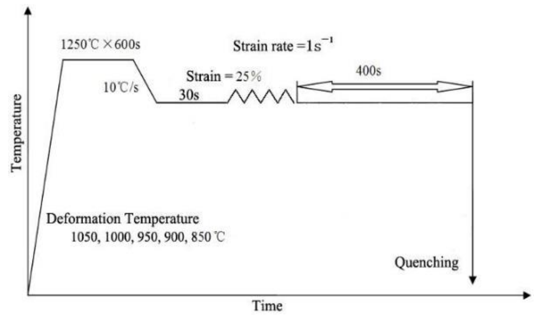
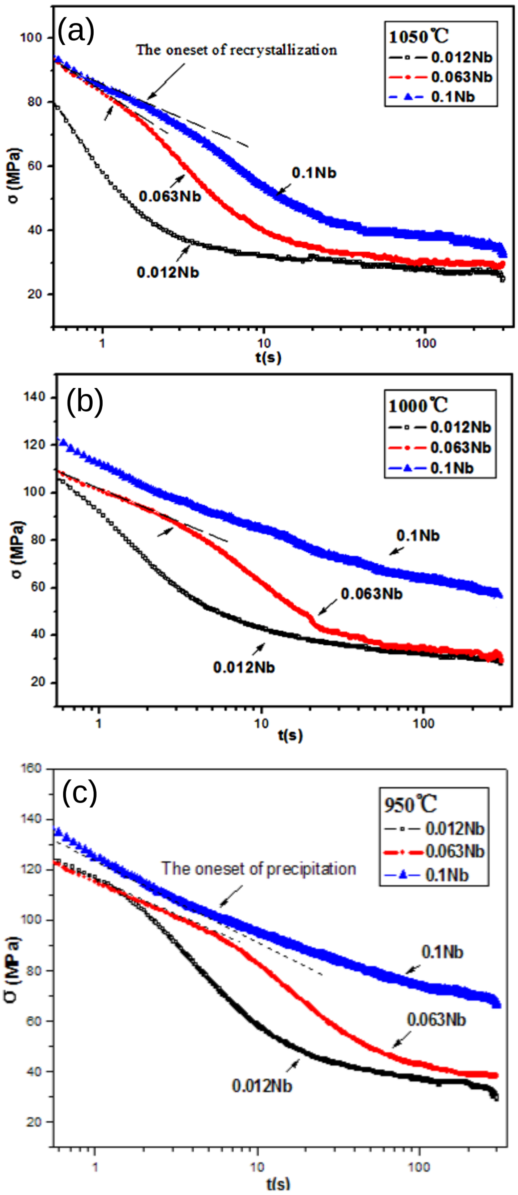


Figure 1. Schematic diagram of stress relaxation test.

and precipitation pinning. It is considered used to characterize recovery or that more precise results can be obtained for isothermal recrystallization kinetics by the stress relaxation method [12].

Figure 2 shows the stress relaxation curves of steels having different Nb contents at 1050°C and 1000°C, 950°C, 900°C and 850°C, respectively. According to figure 2(a), the static recrystallization occurs completely in all three steels after defor-mation, but the onset times of recrystal-lization are different, 0.10%Nb(s3) steel has the longest incubation period, about 2s, meanwhile, the time for the 0.012%Nb(s1) steel is shorter than 0.5s. Moreover, 0.10%Nb (s3) steel needs longer time to complete recrystallization compared with the other two kind of steels.

Likewise, figure 2(b) presents obvious complete recrystallization for the 0.063%Nb (s2) steel and 0.012%Nb (s1) steels at 1000 ºC. Incubation time of recrystallization increased as the temperature decreased. It is interesting to see from the curve of the 0.10% Nb (s3) steel that neither accelerated softening by recrystallization nor sup-pressed softening by precipitation is occurred. It maybe caused by drag effect of solute Nb, which playing the role of inhabiting the static recrystallization at such relative higher temperature. From figure 2 (c) and (d), the curves of the 0.10%Nb (s3) steel at 950ºC and 900ºC both show the softening rates being reduced(5s and 3s, respectively) by strain-induced precipitation.



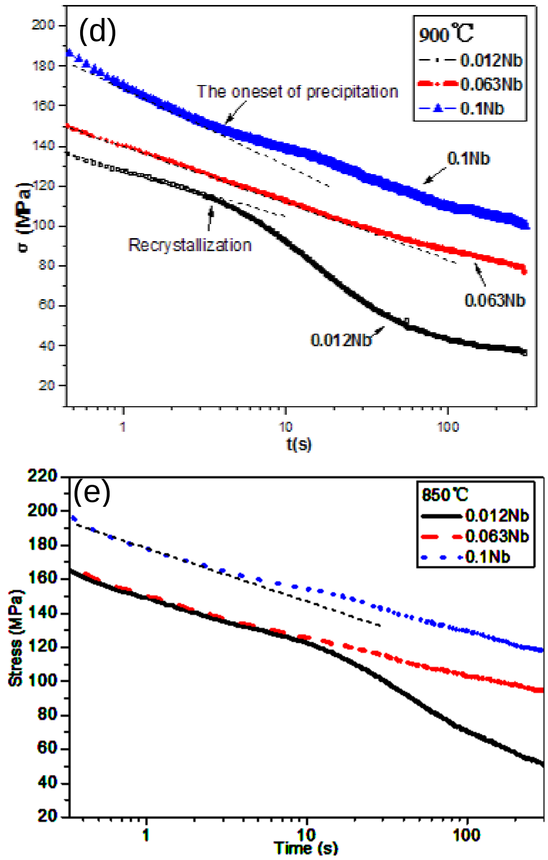
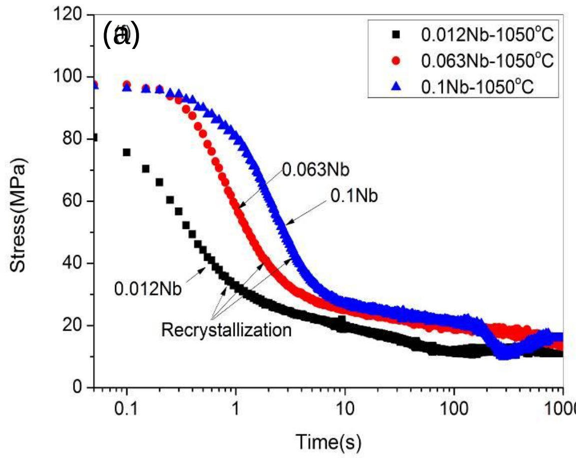
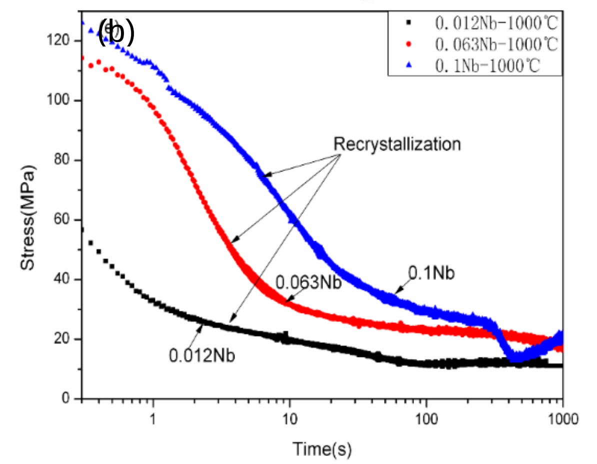


Figure 2. Stress relaxation curves of three steels at (a)1050°C, (b)1000°C,(c)950°C,(d)900°C and (e)850°C, respectively

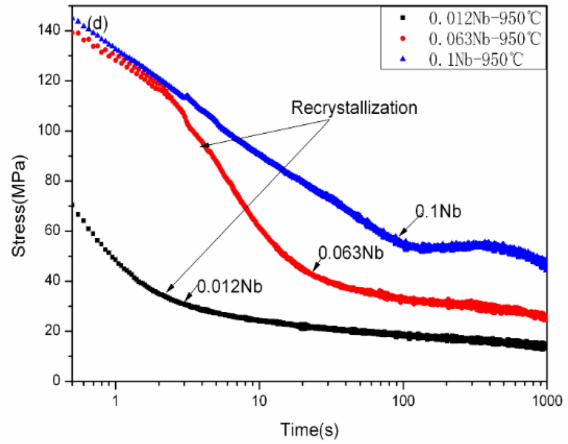
The strain-induced precipitation start time at 900 °C is the fastest (about 3 to 4 s as shown in figure 2 (d)) for the s3 steel. In addition, a clear hardening platform also can be foundfrom the stress relaxation curves at 900℃ for 0.063% Nb steel(figure 2 (d)). However, after deformed at 850℃, no recrystallization is occured for the three kind of steels.

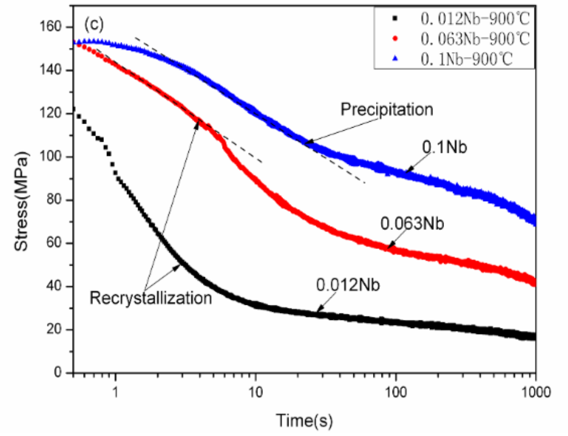
Figure 3 shows the stress relaxation curves of the steels that deformed by 40% at different temperatures (1000℃, 950℃, 900℃, 850℃, 800℃). Figure 3(a) and (b) show the stress relaxation curves at 1050 ℃ and 1000℃, it can be seen that three steels are completely recrystallized. From Figure3 (c), it shows that, the recovery softening process of higher Nb (s3) steel lasts for a long time (about 90s) without recrystal-lization after deformed at 950℃. Meanwhile, the medium (s2) and lower (s1) Nb content steels are completely recrystallized as always. Nevertheless, at 900℃, it can be seen from figure 3(d) that the higher Nb (s3) steel shows that, because of precipitating after 20s of relaxation, the recrystallization is inhibited at all. Meanwhile, from figure 3(e), it shows that there are stress platforms on the stress relaxation curves of high Nb and medium Nb steels just because the precipitates inhibit the recrystallization. Finally, at 800 ℃(figure 3(f)), no recrystallizing process happened at this temperature even with 40% compression.

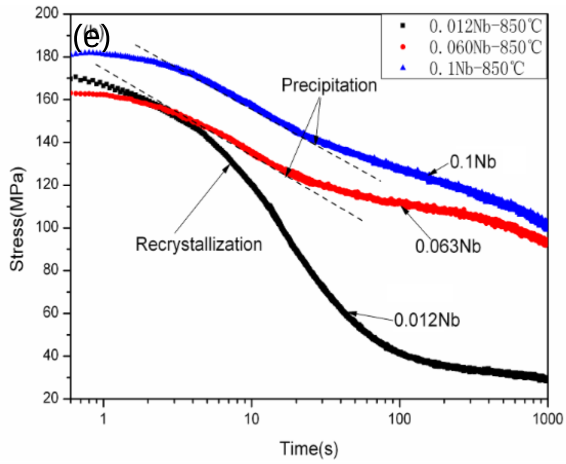




(c)







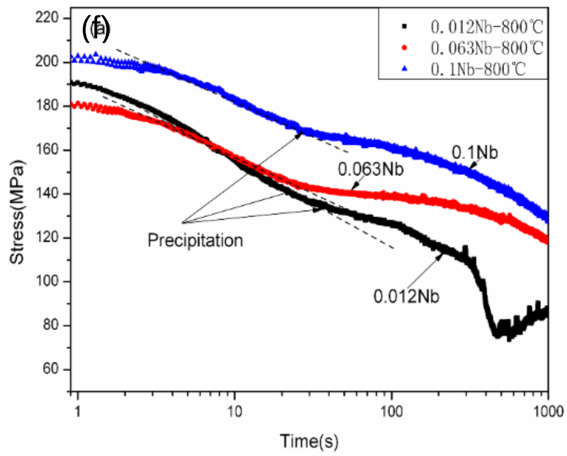


Figure 3 Stress relaxation curves of steels with different Nb content at different temperatures (a) 1050℃(b) 1000 ℃, (c) 950 ℃, (d) 900 ℃, (e) 850 ℃, (f)800 ℃

Effect of austenite grain size on static recrystallization

Related study [14] has shown that, obtaining a smaller initial austenite grain before deformation can accelerate the static recrystallization nucleation rate after deformation. In this paper, the effect of refined prior austenite grains on the static recrystallization behavior of medium and high Nb steels was further studied by the stress relaxation curves after two-pass compression (the simulation process is as shown in Figure 4). The s2 and s3 steel's specimens were heated to 1200 °C for 600 s, then compressed at 1050 °C for 25% to cause complete static recrystallization, and then respectively cooled to 1000 °C, 900 °C deformed for 25%. In the two-pass compression test, the deformation at 1050°C can lead to complete static recrystallization, therefore, prior austenite grain will be refined to 40-50μm[8].

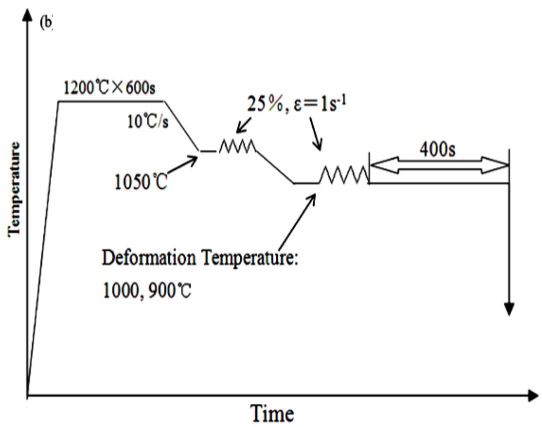


Figure 4 Schematic of stress relaxation process by tow pass deformation

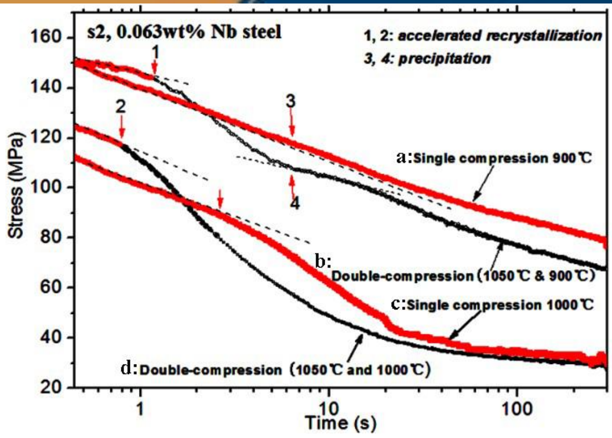


Figure 5 Stress relaxation curves of 0.063Nb (s2) steel at 1000℃ and 900℃ under single and double compression processes

Figure 5 shows the stress relaxation curves for 0.063% Nb (s2) steel under different conditions. Where curve "a" is the stress relaxation curve after deformation 25% at 900 °C by single pass compression as shown in in figure 2(d), curve "b" is the stress after deformation at 900 °C by two passes compression according the process as shown in figure 4, curve "c" is the stress relaxation curve after deformation at 1000 °C by single pass, and curve "d" represents the stress relaxation result of specimen that deformed at 1050°C and 1000 °C, respectively (two-pass). The labels "1" and "2" indicate the inflection points on the curves that were caused by recrystallization, and the numbers "3" and "4" indicate the inflection points on the curves (reduced slope) that were caused by strain-induced precipitation.

From the stress relaxation curves of 0.063 Nb steel (s2), at 1000℃(curves "c" and "d" as show in figure 5), the specimens undergo complete recrystallization after deformation. However, the recrystallization process of two-pass deformation specimen is faster than the single pass one. It implies that finer prior austenite grains can shorten the incubation period of static recrystallization and also accelerate the time for complete recrystallization.

However, if 0.063 Nb steel is compressed at 900℃(as shown by curve "a" and "b" in figure 5), they indicate that under the single pass compression condition, since the incubation period of static recrystal-lization is longer than the incubation period of strain induced precipitation, the static recrystallization behavior of 0.063 Nb steel at 900℃ is completely suppressed for the single compression specimen just because the strain induced precipitation precipitates very quickly after deformation(about 8~9s). The curve “b” shows that after the austenite grains are refined by first pass compression (25%) at 1050°C, the specimen can undergo static recrystallization even at 900 °C, and point “1 ” indicates the static recrystallization starts after 1-2s relaxation. However, the curve “b” also indicates that after relaxing for 6 to 7s, accompanying the

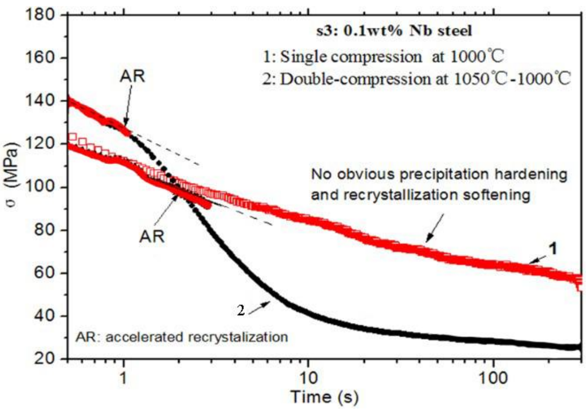


Figure 6 Stress relaxation curve of 0.1Nb steel after deformation at 1000℃ under different process (1:1000℃ single pass 25% deformation, 2:1050℃ deformation by 25%, and then deformed at 1000℃ by 25%)

recrystallization process, the hardening platform appears as shown by point “4”, that means the strain-induced precipitation precipitates and the static recrystallization is suppressed. Therefore, processing at 900 ℃ may cause non-complete static recrystal-lization for the 0.067%Nb steel.

Figure 6 compares the stress relaxation curves of higher Nb (s3) steel under dif-ferent process conditions, including curve 1 (25% single-pass deformation at 1000 °C according to the process as shown in figure 1), and curve 2(the double-pass defor-mation process as shown in figure 4). Curve 1 shows that neither significant precipitation hardening nor recrystallization softening is happened. However, after the prior austenite grains are refined by first pass compression at 1050°C, the static recrystal-lization behavior after 1000 °C deformation will be accelerated, and the static recrystal-lization start time is advanced to about 1 s and ended at about 20 s.

Effect of multi-pass defromation on static and/or dynamic recrystallization

The above experimental results show that the complete recrystallization temperature of Nb-bearing microalloyed steel is only a relative value, which is related to the deformation process, such as deformation, deformation temperature and original austenite size. Figure 7 shows the stress and strain curves of the Nb-containing steels at 950 °C after five passes deformation (each pass deformed 20% with inter-pass time of 12s, simulating the actual rolling process of plate mill). It shows that, the flow stresses of three steels increasing with the increasing of Nb content. It also shows that the mean flow stresses of s1 steel are almost same for five-pass, which means the specimen is completely recrystallized for each pass. Nevertheless, for the higher Nb-bearing steel, the flow stress accumulated in the first and second passes, but the stress-strain curves of the rest three passes are abnormal, the work hardening rate is not stable, that may be caused by dynamic and/or meta-dynamic recrystallization [15] during deformation. The dynamic or meta-dynamic recrystal-lization at a relatively lower temperature [9] can always cause mix grain just because of the non-homogeneous strain accumulation in the matrix, therefore, the static recrystallization rolling window should be optimized to avoid the dynamic and/or meta-dynamic recrystallization.

Theoretically, recrystallization depends on deformation and deformation temperature during austenite process, and Nb content plays most significant role to inhibit grain growth after recrystallization. Form the basic research of recrystallization phenomena of Nb-bearing steels, the characteristics of recrystallization have been released. The recrystallization control rolling process must be implementing according to the recrystallization behaviors of Nb-bearing steel.

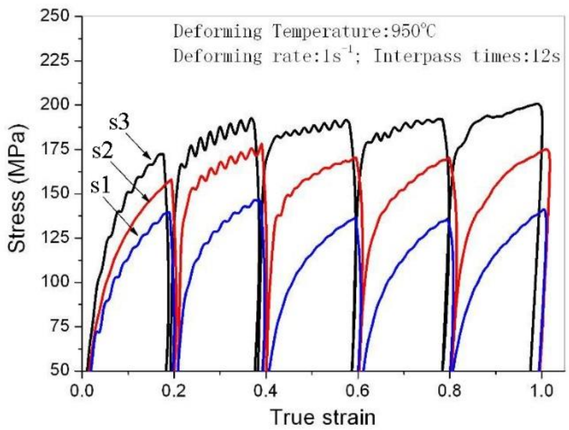


Figure7 True stress-strain curve of multi-pass deformation of Nb-bearing steel

3 Summary

(1) Development of high efficiency gas transmission pipeline will be a long term task for the oil and gas companies in China. The global technology improve-ment for higher capacity and higher safety gas transmission will promote the development of Chinese oil and gas transmission program. High strength pipeline steels contributed greatly to the success of construction high efficiency pipeline projects.

(2) Basic research of recrystallization behavior of Nb-bearing steel shows that with increasing the deformation from 25% to 40%, the complete recrystallization temperature for the 0.1% and 0.063% Nb steels are decreasing from 1050 °C to 1000 °C and 950°C to 900°C, respec-tively. In the same time, refining the austenite grain by multi-pass defor-mation can also promote the static recrystallization both by shorten incubation and complete time.

(3) By five-pass deformation at 950°C with the inter-pass time of 12s, 0.012%Nb and 0.063%Nb steels can be complete recrystallized, but for the 0.1%Nb steel, because of the accumulative and delaying softening of stress, dynamic /meta-dynamic recrystallization would be happened during deformation, therefore, incomplete recrystallization would be occurred and will cause mixed grain of prior-austenite.

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