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DISPERSION STRENGTHENED LOW-ALLOY STEEL

STAL NISKOSTOPOWA UMACNIANA WYDZIELENIOWO

Low-carbon steel with small additions of vanadium and niobium is dispersion strengthenable. After the treatment, yield strength in such steel plates up to 12 mm in thickness can reach 600 MPa, simultaneously retaining impact strength of approx. 100 J/cm^2. After controlled rolling, the steel structure is composed of ferrite and small amounts of pearlite, whereas the grain size in plates up to 12 mm in thickness does not exceed approx. 40 μm. Following normalisation at approx. 950°C, the size of grains decreases and they do not exceed approx. 20 μm.

The technological process of thick plate manufacturing was described in details in technical specifications for steel plates production and also in [5].

On the basis of the data available in the literature [2], rheological investigations into plate material were carried out. The results were used to determine the temperature range in which creep maintains logarithmic character. The results also proved helpful in establishing the dependence (equation) to forecast the material behaviour at elevated temperatures.

Keywords: Dispersion strengthening, low-alloy steel, creep

Stal niskowęglowa z niewielkimi dodatkami wanadu i niobu jest materiałem podatnym na umocnienie wydzieleniowe, po którym granica plastyczności osiąga w blachach o grubości do 12 mm min. 600 MPa, zachowując jednocześnie wysoką udarność rzędu 100 J/cm^2. Po kontrolowanym walcowaniu struktura stali złożona jest z ferrytu i niewielkiej ilości perlitu, a wielkość ziarna w blachach o grubości nie przekraczającej 12 mm nie przewyższa ok. 40 μm. Po normalizowaniu z temperatury ok. 950°C wielkość ziarna maleje i nie przekracza ok. 20 μm.

Proces technologiczny wytwarzania blach grubych został szczegółowo opisany w warunkach technicznych wytwarzania stali w postaci blach, a także w poz. Lit. 5.

Opierając się na danych literaturowych [2] podjęto na materiale blach badania reologiczne, których wyniki posłużyły do określenia zakresu temperatur, w którym pełzanie zachowuje charakter logarytmiczny. Uzyskane wyniki były także pomocne w opracowaniu zależności (równania), pozwalającej na prognozowanie zachowania się materiału w podwyższonych temperaturach.

1. Introduction

Low-alloy steel with niobium, vanadium and nitrogen additions was worked out at the end of the 1970s [1]. In the next decade it was admitted in the construction of crane equipment, its successful application included, among others, telescopic jibs of self-propelled cranes. In the 1990s, on the basis of literature data on steel with a similar composition of micro-additions [2, 3], some creep tests were conducted for 8 mm thick plates of low-carbon steel with vanadium and niobium additions. They were meant to determine the temperature range in which creep maintains logarithmic character and also the creep limit and creep strength. Good properties, such as yield strength, creep limit and creep strength made it possible to file for approval process at the Office of Technical Inspection. The steel was applied to power engineering equipment in the form of plates or pipes. Steel applications were a part of projects co-financed by the Committee for Scientific Research [5].

2. Results and discussion

Research works concerning the structure of the steel have been carried out after various technological operations and the results have led to the following observations:

- the grain size in as-rolled plates does not exceed 40 μm and decreases with the decrease of plate thickness reaching 20 μm in plates 6mm thick,

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- pearlite content does not exceed 5% and is finely dispersed among the ferritic grains,
- the normalization leads to further grain refinement down to approx. 20 μm.

The micrographs of the structure after various technological operations are presented below:

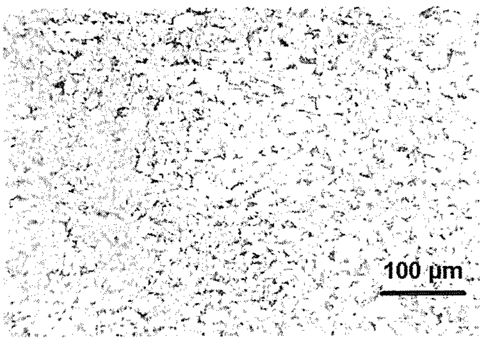


Fig. 1. Microstructure of as-rolled steel plate, after annealing at the temperature approx. 700°C, Nital

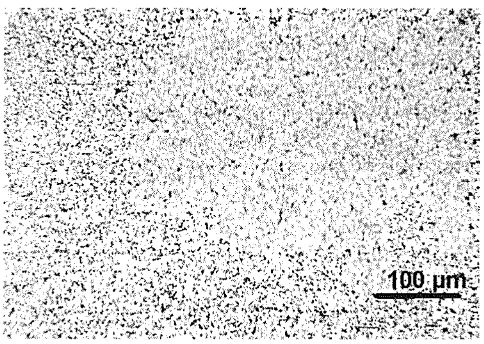


Fig. 2. Microstructure of normalized steel plate at approx. 950°, Nital

The investigations into dispersion strengthening has led to following statements:

- carbonitrides of niobium form mainly on the grain boundaries of ferritic grains and reach the size not exceeding 0.5 μm – Fig. 3
- mixed compounds of niobium and vanadium form inside ferritic grains and reach the particle size of 0.25–0.5 μm; they are frequently elongated – Fig. 3 very fine particles assumed to be vanadium nitrides are dispersed inside the ferritic grain. These particles do not exceed the size 0.02 μm. Distance between them does not exceed 0.05 μm – Fig 4.

Observations provided basis for further works, the conclusion of which was that strengthening can be preserved at elevated temperature, and consequently it increases the creep resistance. The next step were experimental works concerning rheological behaviour of the steel. The chemical composition of the steel used in the research works was as follows: 0.09%C; 1.49%Mn; 0.36%Si; 0.017%P; 0.013%S; 0.12%V; 0.029%Nb; 0.031%Al; 0.010%N. The specimens were prepared out of plates 8 and 12 mm thick under as-rolled and normalized conditions.

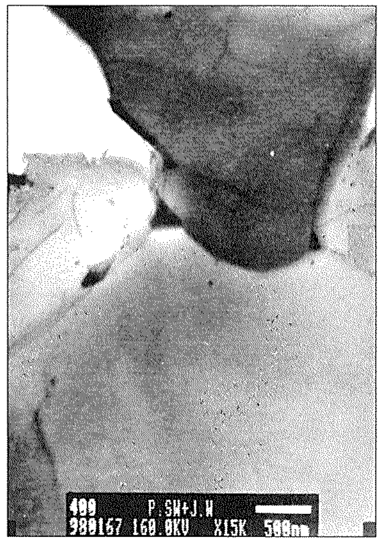


Fig. 3. Precipitates at the grain boundary

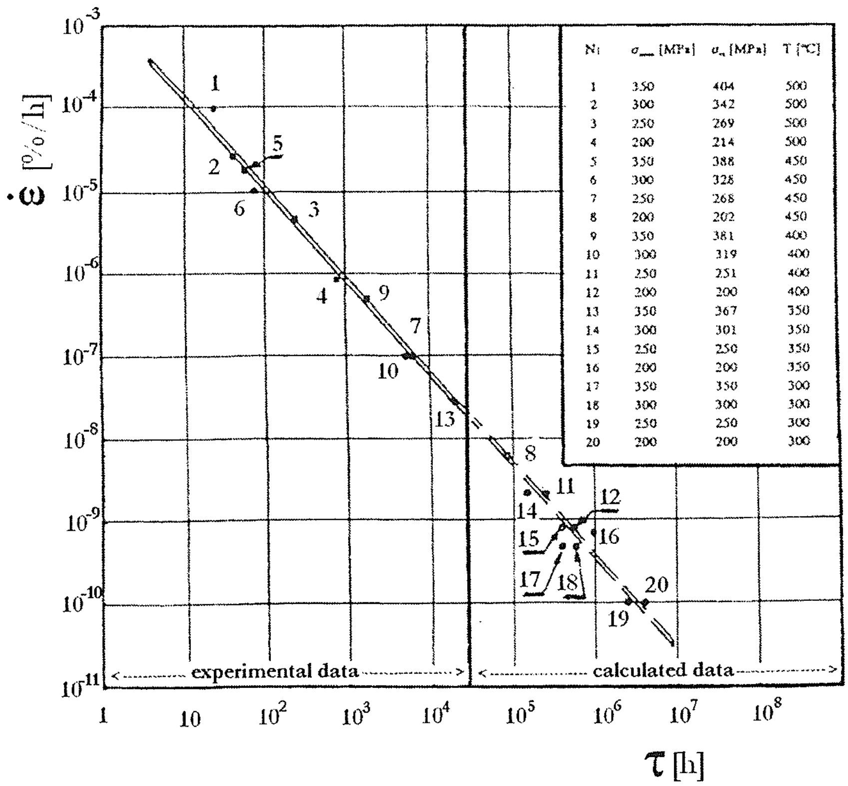
Fig. 4. Finely dispersed particles in the ferritic grains

The experiments were performed in the temperature range up to 500°C and the stress between 200 and 350 MPa for 20,000 hours.

It was observed, that under these conditions only logarithmic creep developed. The results were presented in a graphic form in Fig. 5. These results were also interpreted by relation 1, which makes it possible to forecast the behaviour of the steel. Calculated results were also presented in Fig. 6, in the form of correlation between experimental and calculated values of creep life period.

$$\tau = \frac{\ln\left(\frac{R_{eT}}{\sigma_{nom}}\right)}{10\dot{\varepsilon}_{\%/h}} \tag{1}$$

Relation 1 – makes it possible to forecast the behaviour of the steel up to approx. 500°C, $\dot{\varepsilon}$ – creep rate; R_{eT} – yield strength in elevated temperature; $\tau_{\text{ekstrapol}}$ – extrapolated time.



Ni	σ_{max} [MPa]	σ_n [MPa]	T [°C]
1	350	404	500
2	300	342	500
3	250	269	500
4	200	214	500
5	350	388	450
6	300	328	450
7	250	268	450
8	200	202	450
9	350	381	400
10	300	319	400
11	250	251	400
12	200	200	400
13	350	367	350
14	300	301	350
15	250	250	350
16	200	200	350
17	350	350	300
18	300	300	300
19	250	250	300
20	200	200	300

Fig. 5. Graphic relation between creep rate and time. Up to 20.000 h – experimental data; the further part /over 20.000 h/ – calculated data

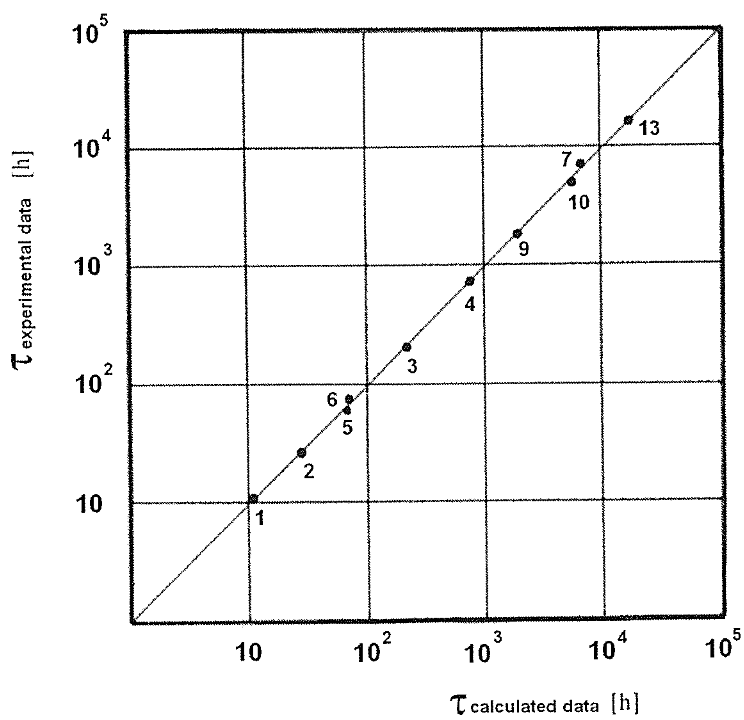


Fig. 6. Correlation between experimental and calculated values of creep life period for Nb-V-N steel

Further investigation works are continued, the experimental data may be important for various applications of the steel in extended temperature range.

In the range up to 20.000 hours, the results obtained from calculations with the use of the proposed equation demonstrate a high convergence with the experimental data. Correlation of the experimental and calculated data is shown in Fig. 6.

3. Conclusions

Properties of low-alloy steel with niobium and vanadium depend on steel grain size and dispersion of precipitations of niobium compounds on grain boundaries and vanadium compounds dispersed inside the ferrite grains.

The steel yield strength after rolling and annealing at the temperature approx. 700°C exceeds 600 MPa at ambient temperature. At higher temperatures strengthening persists and at 500°C it reaches about 360 MPa in 8 mm thick plate material [3].

In the temperature range up to 500°C creep demonstrates a logarithmic character as shown in Fig. 4.

The results of calculations obtained with the proposed equation in the range up to 20.000 hours show a high convergence with the experimental data collected in the steel creep tests. The application of the proposed equation makes it possible to forecast the durability of structures made of low-alloy steel with additions of niobium and vanadium or of similar chemical composition, operating at elevated temperatures.

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