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Structure and mechanical properties of austenitic steel after cold rolling

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Materials

ABSTRACT

Purpose: The aim of the paper is to determine the influence of the cold plastic deformation within the range 18-79% and heat treatment in a temperature range of 500 to 700°C on the microstructure and mechanical properties of austenitic stainless steel grade X5CrNi18-8.

Design/methodology/approach: The investigations included observations of the microstructure on a light microscope, researches of mechanical properties in a static tensile test and hardness measurements made by Vickers's method. The analysis of the phase composition was carried out on the basis of X-ray researches. Whereas, X-ray quantitative phase analysis was carried out by the Averbach Cohen method.

Findings: Heat treatment of X5CrNi18-8 stainless steel in the range 500-700°C causes a significant decrease of the mechanical properties (R_m, $R_{p0.2}$) and increase of elongation (A). Hardness of investigated steel drops with decrease of cold working degree and increase of heat treatment temperature.

Research limitations/implications: The analysis of the obtained results permits to state that the heat treatment causes an essential changes of the microstructure connected with fading of cold deformation. Heating of cold rolled austenitic stainless steels can cause a reverse transformation $\alpha' \rightarrow \gamma$.

Practical implications: Two-phase structure $\alpha'+\gamma$ of austenitic Cr-Ni steel in deformed state working at elevated temperature undergo a transformation. It significantly influences mechanical properties of steel. Austenite phase undergoes a recrystallization, while martensite α' phase undergoes reverse transformation.

Originality/value: The analytic dependence of the yield point of the investigated steel on the cold working degree in cold rolling process has been confirmed. Revealing this relation is of essential practical importance for the technology of sheetmetal forming of austenitic steel.

Keywords: Metallic alloys; Austenitic steel; Plastic deformation; Structure and mechanical properties; Induced martensite

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1. Introduction

Austenitic stainless steels contain most often about 16-25%wt. Cr, 0.1%wt. C and not less than 7.5%wt. Ni, which is necessary to obtain of the single-phase γ structure. In the supersaturated state, these steels are characterized by high elongation A=65% and strength properties: R_m about 550 MPa; $R_{p0.2}$ about 200-250 MPa [1-4].

The specific physical and chemical properties of austenitic Cr-Ni steels as well as their wide industrial applications motivate for continuing many researches on possibility of strength properties increase of austenitic steels by strain hardening in plastic deformation and phase transformation of strengthened austenite as well as precipitation hardening connected with decomposition of supersaturated solid solution [5-7].

The value of strain hardening of austenitic stainless steels mainly depends on chemical compositions determining the stability of austenite. The stability of austenite determines susceptibility of γ phase to martensite transformation and the creating of α` phase. Moreover, the strain hardening depends on parameters of cold working, i.e.: degree of deformation, temperature and deformation rate [8-10].

Two-phase structure α' + γ of austenitic Cr-Ni steels in deformed state working at elevated temperature undergo a change. It significantly influences on mechanical properties of steel. Austenite phase undergoes a recrystallization, while martensitic α' phase undergoes reverse transformation. The mechanism and kinetics of these processes as well as their influence on properties of Cr-Ni steel aren't yet completely known and they are objects of many investigations [11-13].

Thus, the aim of the investigations is to determine the influence of cold rolling and heat treatment on the microstructure and mechanical properties of austenitic Cr-Ni steel grade X5CrNi18-8.

2. Experimental procedure

Investigations were carried out on low carbon metastable austenitic steel grade X5CrNi18-8 [14] with chemical composition given in Table 1. The material for examinations was delivered in the form of sheet-cutting steel with dimensions about 2×100×500 mm, subjected to cold rolling ranging from 18%, 35%, 43%, 60% to 79%, using the sheet mill Quarto type 10502 produced by Skoda. The rolling was conducted at 20°C keeping a constant direction and side of the rolled strip. In the delivery state the X5CrNi18-8 steel is characterized by elongation A=56% and strength properties: R_m about 637 MPa; $R_{p0.2}$ about 335 MPa as well as hardness about 165HV.

Table 1.
Chemical composition of the investigated steel

Mass contents in percentage (%)				
C	Cr	Ni	Mn	Si
0.032	18.43	7.92	1.32	0.452
S	V	Cu	Al	N
0.003	0.097	1.08	0.01	0.057

Cold rolled samples of X5CrNi18-8 steel were heated in a temperature range from 500 to 700°C with a gradation of 50°C. The holding time of samples in such temperature was equal 2 h. Heat treatment in a temperature 500°C and 550°C was realized in box-type furnace PKE2, while in a temperature 600°C, 650°C and 700°C in an electric furnace. The electric furnace was equipped in temperature regulator with an accuracy of ±2ºC.

In order to determine the influence of heat treatment temperature on microstructure and mechanical properties of X5CrNi18-8 steel after cold deformation within the range 18-79% the research of mechanical properties, hardness and microhardness measurements, metallographic observations and X-ray phase analysis were used.

The investigations of mechanical properties were carried out on samples with dimensions about 12.5×80 mm in deformed and heat treatment conditions. Tests were made on the universal testing machine ZWICK 100N5A with a traverse speed of 2 mm/min and a load ranging to 100 kN according to the standard PN-EN 10002-1+AC1:2004 [15].

Hardness and microhardness measurements of the investigated steel X5CrNi18-8 were performed by Vickers's method on metallographic samples using the microhardness tester PMT-3 produced by Hauser. Investigations were made at room temperature in accordance with the standard PN-EN ISO 6507:2007 [16]. Hardness measurements were carried out with a load of 50 N and for the time of about 15 s, whereas in microhardness measurements using a load value about 50 g and time amounting to 10 s were applied. The investigations were made on longitudinal microsections in different steel structure areas after cold deformation within the range 18-79% and heat treatment in a temperature range from 500 to 700°C. The microhardness measurements were realized in austenite grains as well as in areas of martensite α' phase occurring.

Metallographic investigations of the structure were carried out on longitudinal polished microsections of X5CrNi18-8 steel samples after cold rolling and heat treatment. Metallographic observations of the structure were performed on etched specimens. The etching solution was composed of 10 cm^3 HNO_3, 100 cm^3 HCl, 90 cm^3 distilled water. The periods of the etching of individual samples were different. Microscopic examinations of the structure were realized by means optical microscope LEICA MEF4A, using a magnification from 100 to 1000x.

X-ray qualitative and quantitative analysis of cold rolled X5CrNi18-8 austenitic stainless steel were done by means of an X-ray diffractometer type X'PERT PANalytical, applying the filter radiation of an anode λCoK_{α}. The length of radiation (λCoK_{α}) was 0.179021 nm. The data of the diffraction lines were recorded by "step-scanning" method in 2Θ range from 35° to 115° and the 0.05° step, the time of measurements amounting to 10s. X-ray quantitative analysis were carried out on samples with dimensions 10×20 mm cut from X5CrNi18-8 steel after cold rolling and heat treatment in a temperature 500°C and 700°C. Samples for examinations were polished as well as chemical etched in solution with following composition: 10 ml HNO_3, 10 ml HCl and 30 ml $C_3H_5(OH)_3$. The amount of martensite α' phase in X5CrNi18-8 steel was quantitatively measured by the Averbach Cohen method [17].

3. Results and discussion

The metallographic investigations permit to determine the influence of heat treatment on cold rolled steel structure. Particularly to determine the metallographic symptom of heat treatment on shape and size of austenite grains as well as martensite α` phase. The results of metallographic observations are presented on microphotos (Figures 1-5).

In the investigated steel after cold working with a deformation about 18% a structure of austenite grains with the deformation effect of the inside grains were found (Fig. 1). Deformation with a larger deformation degree causes in the steel structure elongated γ grains in the direction of rolling. After cold rolling with 18% and 35% of deformation a few areas of parallel plates characteristic for martensite α' were observed. These areas are characterized by a hardness in a range from 251HV to 353HV.

After 43% of deformation in steel structure the austenite grains about 30 μm average in diameter and microhardness about 225HV and 246HV as well as large areas of martensite α' phase about 283HV of microhardness were observed.

Fig. 1. Structure of the investigated steel after 18% of plastic deformation; Mag. 200x

Metallographic observations of steel structure cold rolled with a deformation from 60% to 79% show the large areas of elongated austenite with small parallel lines of martensitc α' phase (Fig. 2). The hardness in these areas amounts to about 466HV and 447HV.

Fig. 2. Deformed austenite grains and α' phase in the structure of X5CrNi18-8 steel cold rolled with 79% deformation degree; Mag. 500x

After heat treatment in a temperature 550°C of cold rolled steel with 43% of deformation the deformed austenite grains of hardness about 204HV with numerous slip bands as well as areas of martensite α\` phase were disclosed. The size of austenite grains are about 20 μm. The martensite α\` phase was detected in areas of small parallel lines inside austenite grains and in border areas. The microhardness of α\` phase is 329HV (Fig. 3).

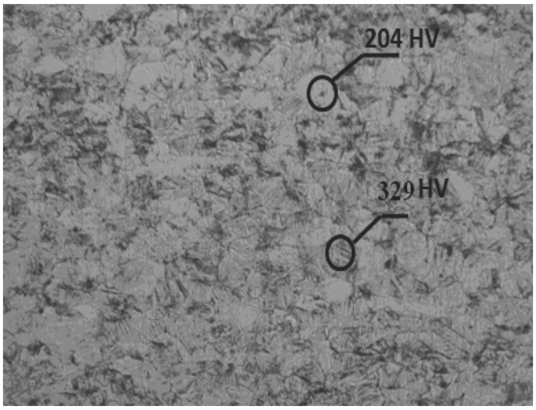

Fig. 3. Deformed austenite grains and α' phase in the structure of X5CrNi18-8 steel cold rolled with 43% deformation degree and heat-treated at 550°C; Mag. 200x

In the structure of the investigated steel after 43% deformation and heat treatment in a temperature of 600°C areas of recrystallized axial austenite grains and elongated grains with distinct effect of deformation were observed. The occurrence of considerable recrystallization areas of γ grains confirms increase of plastic properties and rapid decrease of strength properties after heat treatment of X5CrNi18-8 steel in this temperature.

In steel structure the martensite α\` phase with microhardness of 367HV and 303HV (Fig. 4) was also observed. Numerous slip bands in austenite grains were disclosed (Fig. 5).

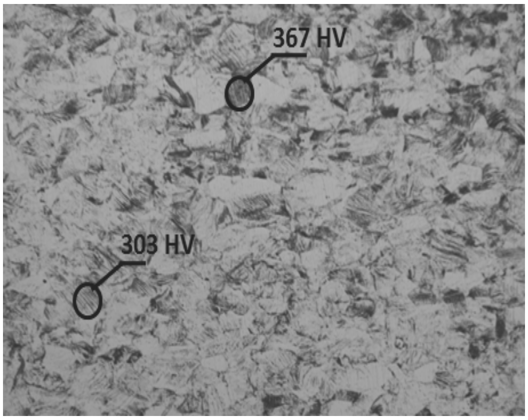

Fig. 4. Deformed austenite grains and α' phase in the structure of X5CrNi18-8 steel cold rolled with 43% deformation degree and heat-treated at 600°C; Mag. 200x

Significant differences in shape and size of austenite grains as well as martensite α\` phase were observed in X5CrNi18-8 steel after heat treatment and deformation from 35 to 60%.

Higher degree of deformation (about 60%) of investigated steel after heat treatment in a temperature 700°C permitted to obtain a super-fine recrystallized austenite grains about size from 2 to 5 μm on background of elongated grains. Next to areas of small grain occur a few elongated γ grains in which the metallographic effect of recrystallization were not observed.

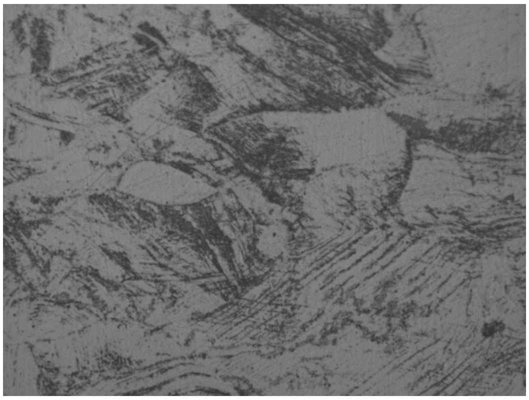

Fig. 5. Austenite grains with slip bands and α' phase in the structure of X5CrNi18-8 steel cold rolled with 43% deformation degree and heat-treated at 600°C; higher magnification of the α' phase shown in Fig. 4; Mag. 1000x

The effect of static tensile tests permitted to quantify the influence of the degree of plastic deformation and heat treatment in the temperature range from 500°C to 700°C on the mechanical properties of austenit X5CrNi18-8 stainless steel. It has been found that heat treatment of cold rolled steel essentially influences its strength and plastic properties.

The increase of temperature in a range from 500°C to 700°C leads to decrease of tensile strength R_m and yield point $R_{p0.2}$ (Figures 6-8).

The heat treatment of cold deformed X5CrNi18-8 steel with 18% deformation degree causes decrease of R_m from 970 MPa to 830 MPa and $R_{p0.2}$ from 800 MPa to 650MPa (Fig. 6). After cold rolling of heat-treated steel with 35% deformation degree the values of R_m and $R_{p0.2}$ decrease from 1200 MPa to 930 MPa as well as from 1030 MPa to 800 MPa (Fig. 7), respectively. With the incensement of deformation within the range of 60% to 79% the tensile strength of the X5CrNi18-8 steel decreases adequately from 1530 MPa to 820 MPa and from 1340 MPa to 850 MPa, whereas the yield point decreases adequately from 1350 MPa to 615 MPa and from 1300 MPa to 650 MPa.

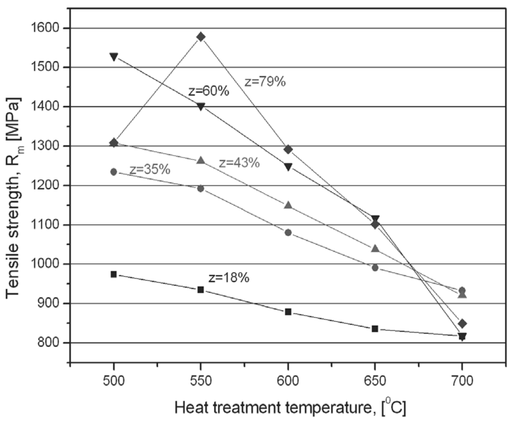

Fig. 6. The influence of the heat treatment temperature and degree of cold deformation (z) on the values of R_m

The elongation of investigated X5CrNi18-8 steel increases with the increase of heat treatment temperature in a range from 500°C to 700°C (Fig. 8). In the cold rolled steel deformed with 18%, 35% and 43% deformation degree the elongation increases adequately from 20% to 32%, from 12% to 25% as well as from 6% to 19% in studied range of heat treatment temperatures. Considerably increase of plasticity was observed for the steel after cold rolling with 60% and 79% deformation degree and heat treatment in a temperature range from 650°C to 700°C. In this range the elongation increased from 10 to 31% for 60% of deformation and from 8 to 30% for 79% of deformation. Recrystallization of austenite and proceed an reverse transformation of deformed martensite causes increasing of steel plasticity. The graph showing dependent on elongation (A) from heat treatment temperature permitted to determine the recrystallization temperature graphically. This temperature is contained in a range from 675ºC to 700ºC for steel rolled with 60% and 79% deformation degree.

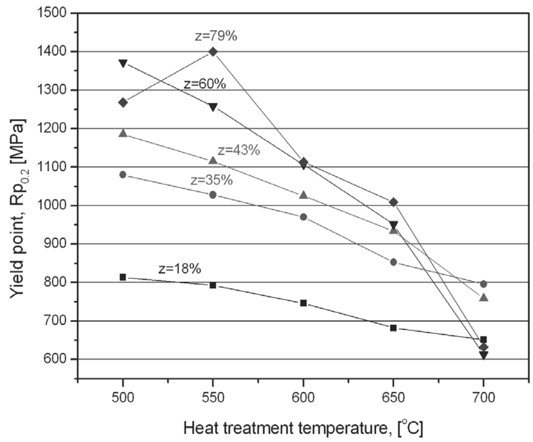

Fig. 7. The influence of the heat treatment temperature and degree of cold deformation (z) on the values of $R_{p0.2}$

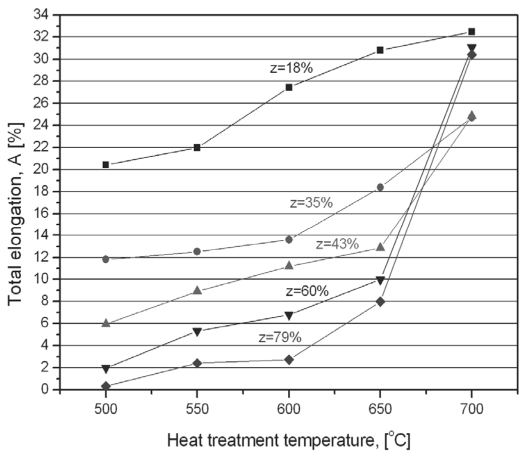

Fig. 8. The influence of the heat treatment temperature and degree of cold deformation (z) on the values of A

The hardness of the examined X5CrNi18-8 steel decreases with decreasing the deformation degree and increasing the heat treatment temperature. With the increasing of heat treatment temperature from 500°C to 700°C the hardness of cold rolled steel with 43% of deformation decreases from 400 to 300HV, whereas in steel deformed with 79% of deformation decreases from 525 to 250HV (Fig. 9).

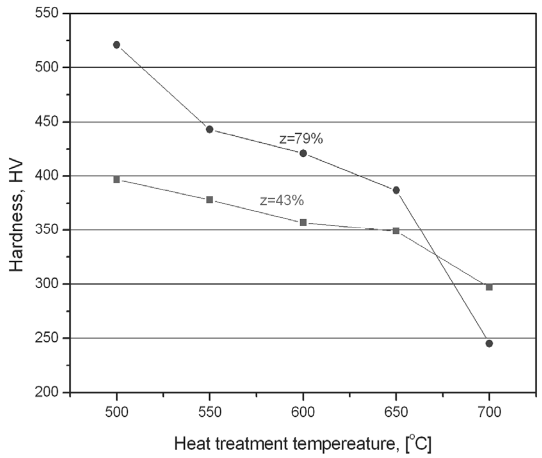

Fig. 9. The influence of the heat treatment temperature and degree of cold deformation (z) on the values of *HV*

On the basis of hardness changes from heat treatment temperature, the recrystallization temperature of austenite matrix was determined. In investigated cold rolled steel deformed with 79% the recrystallization temperature value is about 675°C. The recrystallization temperature for the steel after 43% deformation is over the range of temperatures, which were studied.

In the structure of the cold rolled steel with 43% of deformation and heat treatment in the range of temperature from 500°C to 700°C the microhardness were measured in areas of austenite grains and martensite α’ phase. The microhardness of martensite α’ phase decreases with the increasing of heat treatment temperature, while the microhardness of austenite phase doesn’t change significantly. After heat treatment at temperature of 500°C the microhardness of areas with small parallel lines characteristic for martensite α’ is 466HV, while austenite grains - 325HV and 239HV. The increase of heat treatment temperature to 550°C leads to the decreasing of the α’phase microhardness to value 426HV. After heat treatment at temperature 600°C and 650°C the microhardness of martensite α’ phase is about 367HV, while austenite phase is on the level 254HV and 265HV. The heat treatment in 700°C doesn’t cause a significant differences between the microhardness of austenite and martensite α’ phases. The microhardness in austenite grains is about 255HV and 246HV, while in areas of martensite α’ is about 283HV.

X-ray investigations of X5CrNi18-8 steel deformed from 43% and 79% of deformation and heat-treated in temperature range from 500°C and 700°C show the occurrence of austenite and martensite α’phases in its structure.

On diffraction patterns of steel grade X5CrNi18-8 occurred diffraction lines from γ and α`phases about variable intensity dependent heat treatment temperature. With increasing of heat treatment temperature the amount and intensity of martensite α` phase decreases.

On diffraction patterns of steel deformed with 43% of cold working and heat-treated in 500°C (Fig. 10) occurred diffraction lines coming from planes (111)γ, (220)γ and (311)γ as well as from planes (110), (200), (211) martensite α`phases.

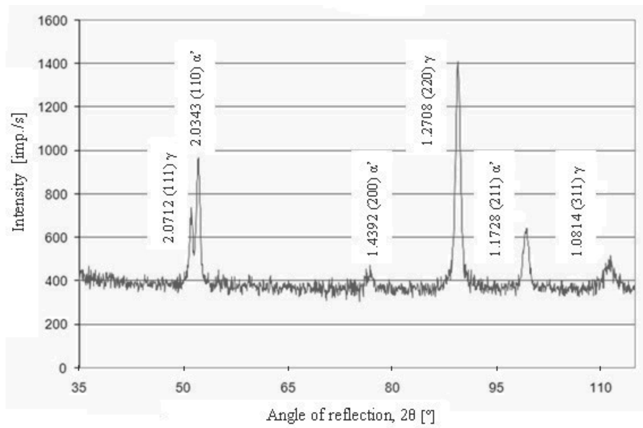

Fig. 10. X-ray diffraction patterns of X5CrNi18-8 steel after 43% of plastic deformation with and heat treatment at 500°C

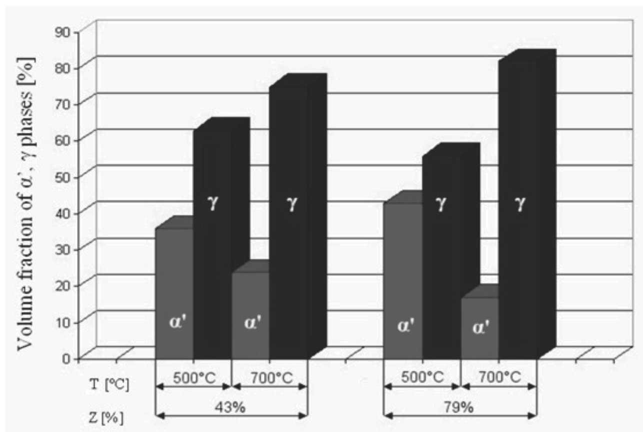

Fig. 11. Volume fraction of γ and α’ phases in structure of X5CrNi18-8 steel after cold deformation (Z) and heat treatment at 500°C and 700°C (T)

The heat treatment of investigated steel in 700°C causes that on diffraction patterns occurred four pikes coming from austenite phase with higher intensity in a temperature of 500°C and two pikes with lower intensity from martensite α’.

The steel after heat treatment in 500°C and subsequently deformed with 79% of deformation show diffraction lines coming from planes (111), (220) of austenite phases and planes (110), (200), (211) of martensite α` phases were found on diffraction patterns. The large degree of cold deformation in the investigated steel induced the martensitic transformation. As the result of phase transformation martensite α` stable up to temperature of 500°C was formed. The heat treatment in 700°C makes possible the proceed of reverse transformation α` → γ. The increase of diffraction lines intensity coming from austenite plane in relation to planes from martensite α` phase testifies about proceed of reverse transformation.

For the calculations a part of the martensite α' phase in the structure of the examined steel dependent on the degree of rolling reduction and heat treatment temperature, the 1% of carbides was accepted.

The increase of heat treatment temperature causes, that the part of martensite α` phase decreases, whereas the increase of deformation degree induces transformation α` → γ and causes increasing the martensite α` phase. With the increasing heat treatment temperature from 500°C to 700°C the amount of martensite α' phases decreases from 36 to 24% for 43% of cold working as well as from 43 to 17% for 79% of cold working (Fig. 11).

4. Conclusions

The obtained results of investigations lead to the following conclusions:

- The heat treatment of cold rolled X5CrNi18-8 steel in a temperature range from 500°C to 700°C causes significant decrease of strength properties and meaningful increase of plasticity. Minimum values of R_m and $R_{p0.2}$ as well as maximum elongation *A* studied steel shows after 60% of cold plastic deformation and heat treatment in a temperature 700°C. These properties accept following values: R_m about 800 MPa, $R_{p0.2}$ about 600 MPa, *A* about 30%.
- The hardness of the examined steel decreases with decreasing of the deformation degree and increasing of heat treatment temperature.
- Austenitic steel grade X5CrNi18-8 after cold plastic deformation and heat treatment in the studied range of temperatures shows the structure of austenite grains with areas of martensite α`phase.
- The amount of martensite α' phase decreases from 36 to 24% for 43% of cold working as well as from 43 to 17% for 79% of cold working with the increasing heat treatment temperature from 500°C to 700°C.

Acknowledgements

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