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Tool-steel Wire Drawing at Elevated Temperatures

Vlečenje žice iz orodnih jekel pri povišanih temperaturah

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Tool steels have in cold state very low workability, therefore they must be frequently recrystallization annealed during the cold drawing process, but some types of steels cannot be cold drawn at all. Their working properties are highly improved at elevated temperatures. This paper analyzes the drawability of wire, made of BRM2 (W.NR-1.3343) steel, and it describes the technology of wire drawing at temperatures up to 700°C.

Orodna jekla imajo v hladnem stanju zelo slabe preoblikovalne sposobnosti, zato jih moramo med hladnim vlečenjem velikokrat rekristalizacijsko žariti, nekatera jekla pa hladnega vlečenja sploh ne prenesejo. Njihove preoblikovalne sposobnosti se precej izboljšajo pri povišanih temperaturah. V delu smo ugotavljali vlečne sposobnosti žice iz jekla BRM2 (W.NR-1.3343) in opisali tehnologijo vlečenja žice pri temperaturah do 700°C.

1 Introduction

High-speed tool steel of BRM2 type is mainly used for tools and spiral drills for machining of steels and alloys, and for manufacturing of high-quality wear-resistant tools. Wear resistance of steel is achieved by a great number of fine secondary carbides which are in the ferritic matrix of steel. Carbides do not give only a high wear resistance of steel but they also contribute to an intensive hardening of steel in cold workability. Thus the wire made of BRM2 steel can sustain in cold drawing almost 20% partial and approximately 45% total reduction degree, therefore it must be more than six times intermediately recrystallization annealed in drawing from 8 to 2 mm diameter. Such a manufacturing of fine wire is rather expensive and long lasting.

Drawability of steel is rather improved at elevated temperatures when wire can be drawn to fine dimensions without intermediate recrystallization annealing. The first drawing tests at elevated temperatures (worm drawing) were made with shorter lengths of wires, and it was found that wire can be drawn at 700°C even to the diameter of 3 mm. Based on results of drawing tests to thin dimension wires, which will be described in details, the technology for worm drawing of wires in coils was prepared.

2 Drawability of the steel at elevated temperatures

Drawing tests of thin wires showed that drawability of BRM2 steel is optimal at 700°C and 15% reduction degree. Drawability of the steel was determined from numbers of draws which wire sustained at various temperatures and from yield stresses calculated by following mathematical expression:

$$q_m = \frac{F_i}{\Delta A_i},$$

where is:

- q_m yield stress in N/mm^2,
- F_i drawing force in N/mm^2 and
- ΔA_i cross-section reduction in single draw in mm^2.

Yield stresses and number of draws, which wire of BRM2 steel sustained at various drawing temperatures, are presented in **Fig. 1.** The plot shows that the wire sustains

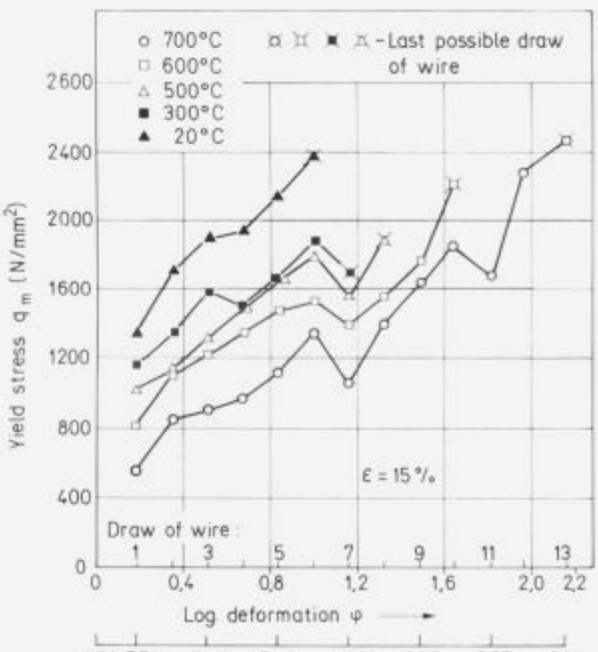

Figure 1. Yield stresses at wire drawing of BRM2 steel at elevated temperatures.
Slika 1. Preoblikovalne napetosti pri vlečenju žice iz jekla BRM2 pri različnih temperaturah.

the cold-drawing reduction without recrystallization annealing from 8 to 5.5 mm. It can sustain some more draws at temperatures up to 550°C, while at 700°C it can be reduced even to 3 mm. Good workability of the steel can be judged also by yield stresses which values at 700°C are half of the values like in cold drawing. In hot drawing of the wire the recrystallization annealing is not needed since recovery is achieved by heating wire to the drawing temperature and during the drawing process, and at higher temperatures also recrystallization probably occurs. The described tests were made with 2 to 3 m long wire pieces on drawing bench with a drawing velocity of 0.25 m/s. Drawing conditions on a drawing bench are less demanding than in coil drawing. Therefore wire in coil drawing sustains less draws.

3 Technology of wire drawing at elevated temperatures

The aim in preparing the technology of wire drawing at elevated temperatures was to apply the existent equipment for cold drawing to the maximal extent. This on one side reduces the developing costs of the technology, and on the other side it enables cheaper and simpler transmission of the technology into industrial practice. The scheme of thus designed and also tested line is given in **Fig. 2,** while **Fig. 3** shows the picture of it.

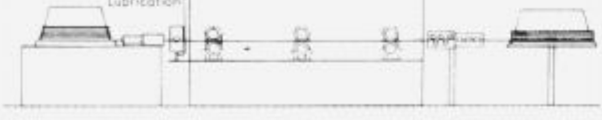

Figure 2. Scheme of wire-drawing line at elevated temperatures.
Slika 2. Shema linije za vlečenje žice pri povišanih temperaturah.

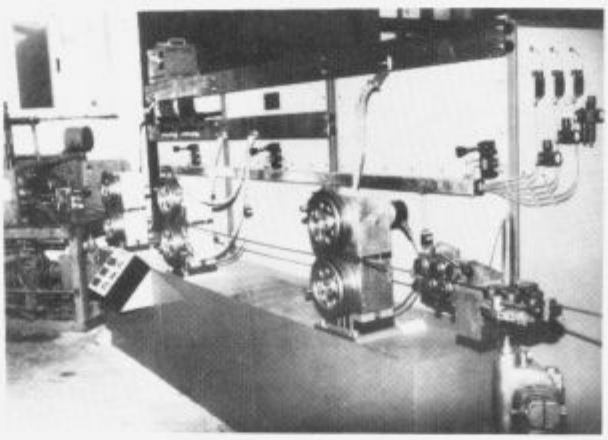

Figure 3. Picture of wire-drawing line at elevated temperatures, built at the Institute of Metals and Technologies in Ljubljana.
Slika 3. Izgled linije za vlečenje žice pri povišanih temperaturah, ki je postavljena na Inštitutu za kovinske materiale in tehnologije v Ljubljani.

The presented line consists of three basic units:

- equipment for conductive heating of wire,
- equipment for temperature measurements on wire during the drawing and
- drawing machine.

In front of the heating equipment also frame for uncoiling and straightening rollers were mounted. In the whole installation only the conductive heating equipment for wire was new. Wire is heated by three pairs of contact rolls. The basic characteristics of the three mentioned units are:

3.1 Heating Equipment

This equipment was purchased at Montanstahl, Switzerland. Its power is 90 kVA, and this was chosen according to the greatest desired diameter 8 mm of heated wire, the highest wire temperature 800°C, and the drawing velocity 0.28 m/s. Heating of wire is a two-stage process. In the interval between the first and second pair of rolls the wire can be heated at most up to 500°C, and between the second and the third pair the temperature is raised further to 800°C. Heating power is adjusted manually while the equipment contains also driwer which prevent overheating of wire in the case of stoppages during the drawing process.

3.2 Equipment for Measuring Wire Temperature

Wire temperature is measured with optical pyrometer. Measuring system is not connected with the heating system, therefore the heating power is regulated manually according to the registrated temperature.

3.3 Drawing machine

Drawing machine is designed for cold drawing of wires thinner than 8 mm. Therefore the drawing drum is constructed in such a way that drawn wire in cold drawing slips uniformly along the drum. Drawing conditions are during the cold drawing rather unchanged. In worm drawing the conditions are changing according to the temperature of worm drawing, wire diameter, and lubrication. In the first worm-drawing tests with the described equipment, slippage of wire on the drawing drum in the upward direction occured, while overlapping of wire windings was experienced with thinner wire. Both phenomena made drawing impossible. The described troubles were solved by mounting special guides for drawn wire which were fixed around the drawing drum. The mentioned guides can be dismounted from the drum after worm drawing so that the same drawing machine can be used also for cold drawing of wire.

Efficiency of worm drawing of wire does not depend only on the sliding of wire along the drawing drum but also on the preparation of wire surface before drawing, on the quality of lubrication, and thus also on the drawing temperature and the wear resistance of dies.

3.4 Preparation of Wire Surface

Efficiency of conductive or contact heating depends a great deal on the quality of contacts between the pair of heating rolls and the heating wire. In bad contacts sparking, incipient melting and quenching of heated wire on contact area can occur. Such an area does not sustain deformation in drawing, and wire breaks. Sparking can occur on badly descaled or rusted areas of wire, therefore the wire surface must be well prepared before drawing. According to the experiences obtained so far, the sandblasted wire surface is the most suitable one especially if it is also copperized. Sandblasted surface is rougher than a pickled one, and thus adhesion of lubricant on the wire surface before drawing is better. Copperizing on the other hand prevents rusting of wire after the drawing.

3.5 Lubrication

In worm drawing lubrication is less effective than in cold drawing, therefore the wire cannot stand higher partial deformations degree than 15%. Graphite was used as lubricant since it was in the regard to persistance and price the only acceptable lubricant which could stand drawing also at temperatures above 500° C. Graphite has good lubrication properties but its adherence to the wire surface is unfortunately weak, therefore it was applied in form of oil paste. Paste has good lubrication power up to 650° C, at higher temperatures its lubrication power is rather reduced due to reduced adherence to the wire surface. Ground and flaky graphite was tested too. A little better lubrication was achieved with flaky graphite but it is rather more expensive. In hot drawing the greatest troubles are caused in lubrication. This problem is not suitably solved, therefore some manufacturerers of fine sections of special steel have substituted hot drawing with rather more expensive microrolling process, where all the problems with lubrication are avoided.

3.6 Wear Resistance of Dies

In drawing hard-metal dies are used so far, but they have good wear resistance only up to 300 or 400° C. At higher temperatures their wear resistance is rather reduced, therefore also ceramic dies, made of silicon carbide, were tested. The mentioned ceramic material has a very good wear resistance even up to 1000° C, but its disadvantages is a low resistance to temperature shocks and its brittleness. In cold and hot drawing tests it was found that ceramic materials stood the drawing process therefore the tests of drawing through ceramic dies will be continued.

In developing the technology of hot drawing of wire a great attention was given also to the yield of drawn wire which is lower than in cold drawing. In hot drawing the beginning and the end of wire coil must be drawn cold. Since BRM2 wire sustains only two coil draws the cold drawn ends should be cut off. Thus the yield of drawn wire is reduced. A trial was made to avoid cutting-off the wire ends by welding another material with good workability on the wire end. The mentioned solution proved as unsuitable due to too long needed times of soft annealing the weld. Therefore the problem was solved by annealing the cold drawn wire ends. For this purpose a special conductive equipment for wire-end annealing was built which enabled annealing of 5 m lengths and thus the yield of BRM2 wire in hot drawing was increased to 100% nearly.

4 Conclusion

Drawing of wire at elevated temperatures rather differs from the cold drawing, therefore many problems appeared in development the drawing technology at elevated temperatures, which were more or less successfully solved to such an extent that already industrial drawing line for wire coils exists. So far over 1500 kg wire of BRM2 steel was drawn from 8 mm to various finer dimensions. The finest diameter of drawn wire was 3,2 mm. The line is improved to such an extent that a large-scale production is negotiated with the Ravne Iron and Steelworks as the tool-steel producer. Double applicability of drawing equipment, i.e. for cold and hot drawing, the developed technology is much cheaper than the competitive microrolling, and it is suitable mainly for smaller manufacturers of various tool steels.

5 References

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