DEGRADATION OF THE STRUCTURE AND MECHANICAL PROPERTIES
OF THE LVN13 ALLOY INDUCED BY LONG-TIME EXPOSURE
TO HIGH TEMPERATURES

Božena Podhorná\textsuperscript{a}
Jitka Kabátová\textsuperscript{a}
Karel Hrbáček\textsuperscript{b}
Antonín Joch\textsuperscript{b}

\textsuperscript{a}UJP PRAHA a.s., Nad Kamínkou 1345, 156 10 Praha – Zbraslav, e-mail: podhorna@ujp.cz
\textsuperscript{b}PBS Velká Bítěš a.s. Vlkovská 279, 595 12 Velká Bítěš, e-mail:hrbacek.karel@pbsvb.cz

Abstract
The paper summarizes the results of investigation into the structure stability and mechanical properties the LVN13 creep-resisting cast alloy hardened by $\gamma'$ phase. The alloy was subjected to long-term annealing at 700°C, which is the working temperature at which castings made of this alloy would be used in industrial applications. The changes in the microstructure and basic mechanical properties induced by the long-term exposure to the high temperature are described and evaluated.

Keywords: LVN13 alloy, structure stability, intermetallic phase, mechanical, properties

1. INTRODUCTION

The LVN13 alloy is a heat-resistant cast austenitic chrome-nickel steel hardened by the $\gamma'$ $\text{Ni}_3(\text{Al,Ti})$ intermetallic phase. Alloys of this type are not widely used because of practical problems associated with their casting, preference being given to nickel steels with lower alloying element contents. In fact, nickel steels are more expensive and their properties are actually not fully utilized in the casting, but the fact that fewer problems are encountered outweigh the higher price. Financial aspects, however, are becoming more and more important, and as a deeper insight into the metallurgy of materials of this type is being gained, alloys such as LVN13 appear to be very promising. In view of this, PBS Velká Bítěš has been pursuing the development of the LVN13 alloy for a few years now.

2. MATERIAL

The LVN13 alloy is basically a modification of the LVN3 (15Cr32NiMoWTiAlB) alloy as regards its chemical composition, and is obtained by using a specific heat treatment regime. The steel is alloyed with 35 wt.% nickel and 15 wt.% chromium. Alloying with aluminium and titanium, which form the $\gamma'$ $\text{Ni}_3(\text{Al,Ti})$ hardening phase in the alloy, is important in order to obtain a good heat resistance. Strengthening the solid solution with molybdenum and tungsten also contributes to a good heat resistance up to 750°C.

Metallurgical problems due to a poorer casting ability of austenitic steels were basically obviated by lowering the carbon level and by alloying with boron. Metallographic analysis revealed that the presence of boron affects appreciably the separation of primary phases at the boundaries of the casting cells of the casting structure. Also, the primary particles separated on the boundaries of the casting cells are finer and their total volume is lower [2]. This makes for good casting properties during casting in a vacuum using the precision investment casting technology. The prescribed chemical composition of the LVN13 alloy is given in Table 1.
Table 1. Chemical composition [wt.%]

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Cr</th>
<th>Mo</th>
<th>Al</th>
<th>Ti</th>
<th>Fe</th>
<th>W</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>max.</td>
<td>0.03</td>
<td>14.0 – 16.0</td>
<td>0.80 – 1.50</td>
<td>2.50 – 3.50</td>
<td>0.80 – 1.20</td>
<td>base</td>
<td>2.50 – 3.50</td>
<td>max. 0.50</td>
</tr>
<tr>
<td>Ta</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>max. 0.015</td>
<td>max. 0.50</td>
<td>max. 0.015</td>
<td>0.08 – 0.12</td>
<td>30.0 – 35.0</td>
</tr>
<tr>
<td>Zr</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nb</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The optimum mechanical properties and optimum creep strength are obtained on heat treatment in the following conditions [3, 4]:

1150 °C/2h/argon (vacuum) + 750 °C/20h/air.

Two additional heat treatment variants, which would be more economical [5, 6], were also studied:

1080 °C/4 h/air + 750 °C/20 h/air,
750 °C/24 h/air.

A lower annealing temperature implies lower energy demands and, owing to the alloy’s very good corrosion resistance at elevated temperatures, offers opportunities for achieving additional savings through annealing in air. Tensile yield strength at 20°C increased by more than 100 MPa in all the heat treatment regimes applied. The improved levels remained preserved up to 700°C. Differences between the various heat treatment regimes were minimal. The mechanical properties of the LVN13 alloy were only slightly affected by omitting the dissolution annealing step: in fact, only the tensile strength decreased slightly. The remaining mechanical properties measured remained virtually unaffected.

The microstructure of the as-cast LVN 13 alloy is shown in Fig. 1. It includes an austenitic matrix where coarse particles of the primarily separated carbides and the γ´ phase are present on the boundaries of the casting structure cells. Globular particles of borides of the M_3B_2 type can also separate on the boundaries of the dendritic cells. The process of hardening of the base material by the γ´ secondary phase, which separates in a very fine form, is highly inhomogeneous. It starts on the boundary of the casting cells, where the concentration of Ti and Al is presumably higher and thus the conditions for the formation of such particles are more favourable.

The microstructure of the as-treated alloy following heat treatment by the simplest variant, i.e. by hardening annealing at 750°C only, is shown in Fig. 2. No changes in the primarily separated particles on the boundaries of the casting cells occur at that hardening annealing temperature. A slight coarsening of the γ´ phase particles and only a slow propagation of precipitation from the casting cell boundaries to the cell centres occur during holdup at the temperature. It can be inferred that dissolution annealing results in a more uniform chemical composition, manifesting itself in the dissolution of the fine particles separated in the area of the maximum segregation of the additions.
3. STRUCTURE STABILITY AFTER LONG-TIME ANNEALING

In view of the expected use of the LVN13 alloy in the newly developed parts of impellers and stators of new generation turbo-blowers it was necessary to examine the structure stability and mechanical properties of the alloy following a long holdup at the operational temperature. Metallographic specimens in the form of cylinders 20 mm long and 15 mm in diameter were exposed to long-time exploitation at 700°C. The holdup times were 50, 100, 500, 1000, 2000 and 5000 hours. Following such holdup, the microstructure and Vickers hardness (HV 30) were evaluated for the specimens. The hardness data revealed that additional alloy hardening takes place during annealing for 50 hours, which continues slightly up to 200 hours. Additional hardness increase was observed in 1000 hours of holdup at 700°C, which continued up to the holdup time of 5000 hours. This hardness improvement is significant to the extent that the separation of new hard phases responsible for this phenomenon can be assumed. The effect of the long-time annealing on the hardness of the alloy is shown in Fig. 3.

![Microstructure of the as-cast LVN13 alloy](image1)

**Fig. 1. Microstructure of the as-cast LVN13 alloy**

![Microstructure of the as-treated LVN13 alloy](image2)

**Fig. 2. Microstructure of the as-treated LVN13 alloy**

![Effect of long-term annealing of the LVN13 alloy on its hardness](image3)

**Fig. 3. Effect of long-term annealing of the LVN13 alloy on its hardness**

![Microstructure of the LVN13 alloy following annealing at 700°C/50h](image4)

**Fig. 4. Microstructure of the LVN13 alloy following annealing at 700°C/50h**

The structure of the alloy after 50 hours of holdup at 700°C is shown in Fig. 4. Additional hardening by separation of the very fine γ' phase took place. This state remained unchanged up to 500 hours. In 1000 hours of annealing, a new phase – presumably the σ phase – separated, especially in the dark areas of rather intensive separation of the γ' phase (Fig. 5). In 5000 hours of annealing the material was degraded completely and separation of the intermetallic phase was very intense (Fig. 6). The structure correlated well with the hardness.
4. EFFECT OF LONG-TIME ANNEALING ON THE MECHANICAL PROPERTIES

Isothermal annealing at 700 °C was also applied to specimens having the form of rods approx. 80 mm long and 15 mm diameter. The specimens served to prepare samples for the determination of tensile strength, elongation and notch toughness parameters during 2000 hours of holdup at the above temperature. The mechanical properties of the material subjected to heat treatment at 750 °C/20h (as-treated alloy) or heat treatment with subsequent long-time annealing (as-exposed alloy) are compared in Figs 7-10 below.

![Fig. 7. Comparison of the tensile yield strength after heat treatment and after annealing at 700 °C/2000h](image1)

![Fig. 8. Comparison of the ultimate tensile strength after heat treatment and after annealing at 700 °C/2000h](image2)

![Fig. 9. Comparison of elongation after heat treatment and after annealing at 700 °C/2000h](image3)

![Fig. 10. Comparison of notch toughness after heat treatment and after annealing at 700 °C/2000h](image4)
Comparison of information gained from mechanical tests bears out what has been found by hardness measurement and structure analysis. Long-term annealing, associated with hardening, brought about increase in both the tensile yield strength and ultimate tensile strength. This strength increase, however, is associated with an appreciable decrease in both the alloy's elongation and notch toughness. As to the notch toughness, the values after 2000 hours of annealing were even mere one-half as compared to those following heat treatment.

5. EFFECT OF THE ALUMINIUM CONTENT ON THE PROPERTIES OF THE ALLOY

As found previously [3], mechanical properties of steels that have been precipitation-hardened by the γ' phase depend, among other things, on the aluminium content of the alloy. The addition of aluminium as an alloying element can bring about improvement of the use properties of the alloy without any price change. Increase in the aluminium content results in an increase in the volumetric proportion of the γ' phase. The size and distribution of the precipitates can be controlled via the heat treatment regime. A higher dissolution annealing temperature can be expected to bring about a more homogeneous separation of a finer precipitate, resulting in improved mechanical properties. However, an increased aluminium content can induce the formation of unwanted intermetallic phases in the steel structure, ultimately resulting in poorer mechanical properties. As regards the LVN13 alloy, it was found that if aluminium is present at 3.9 wt.%, appreciable separation of the σ-phase and of the Laves phase takes place at temperatures above 700°C and at about 1000°C, respectively. Precipitation of the σ-phase manifests itself in the typical platelet-like morphology. Our tests gave evidence that even a temperature of mere 700°C is too high for the structure stability of the steel to be maintained, and if the system is held at that temperature for a long time, the unwanted σ-starts to precipitate in 1000 hours and the precipitation process is quite appreciable in 5000 hours of annealing. The chemical composition of the alloy was checked by using an EDS analyzer, and the aluminium content was found to be at the limiting level of 3.9 wt. %.

6. CONCLUSIONS

The effect of long-term exposure to a temperature of 700°C on the structure stability and degradation of the mechanical properties of the LVN13 alloy was examined. The following facts were ascertained:

- Long-time annealing at 700°C brings about a permanent hardness increase. Metallographic analysis showed that up to 500 hours of annealing the increased hardness can be ascribed to additional hardening of the alloy. After 1000 hours of annealing, however, the intermetallic σ-phase separates, which process is very intensive after 5000 hours of annealing.
- Chemical analysis revealed that the aluminium content is at the limiting level of 3.9 wt.%. Such aluminium content gives rise to preconditions for the formation of intermetallic phases in the steel structure.
- The results of mechanical tests are in line with the results of hardness measurements and structure analysis. Long-term annealing brought about increase in both the tensile yield strength and ultimate tensile strength due to the hardening process occurring in the alloy. This strength increase, however, is associated with an appreciable decrease in the alloy's elongation and notch toughness. The notch toughness level after 2000 hours of annealing was mere one-half of that measured after heat treatment.

The results of this study suggest that if the LVN13 alloy should be deployed to replace the more expensive nickel alloys in their current applications, then the alloy with the current aluminium content should be subjected to annealing at 650°C, and additional variants with lower aluminium contents should be tested.
ACKNOWLEDGMENT

This investigation into the structure and properties of the heat-resistant LVN13 alloy was performed within the Tandem programme subsidized by the Czech Ministry of Industry and Trade.

REFERENCES

