RESEARCH INTO PROPERTIES OF NICKEL-BASED SUPERALLOYS FOR GLASSWORKS

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VÝSKUM VLASTNOSTÍ SUPERZLIATIN NA BÁZE NIKLU VHODNÝCH NA POUŽITIE V SKLÁRSTVE

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Abstrakt

V Prvej brnenskej strojárni Veľká Bíteš bola vyvinutá technológia presného odlievania častí vhodných na použitie v sklárskom priemysle. Ako konštrukčný materiál sa použili superzliatiny na báze nikla, označované 141, 141H, 141I, 145 a 2.4879. Zistili sa mechanické vlastnosti týchto zliatin a ich stabilita štruktúry v intervale teplôt < 20; 1100> °C.

Výskum bol zameraný na problematiku dejov v štruktúre, ktoré prebiehajú pri vysokých teplotách a na objasňovanie vzťahov medzi štruktúrou a mechanickými vlastnosťami novozavádzaných superzliatin. Hlavným cieľom bolo získať údaje o vplyve chemického zloženia vedúceho k optimalizácii výberu týchto zliatin, získať dostatočné informácie o ich stabilite štruktúry, o základných mechanických vlastnostiach týchto zliatin a o ich degradácii počas dlhodobého účinku teploty tak, aby sa vytvorila spoľahlivá databáza údajov pre konštrukčné riešenie odliatkov pri ich zavádzaní do technickej praxe.

Abstract

The *První brněnská strojírna Velká Bíteš* Company has developed a process of precise casting suitable for parts to be used in glass industry. The parts were made of nickel-based superalloys designated 141, 141H, 141I, 145 and 2.4879. The mechanical properties and structural stability of the alloys were determined within the temperature range of < 20; 1100>°C.

The research aimed to study the issues of structure-related processes occurring at high temperatures, and to reveal the relation between structure and mechanical properties in the superalloys being newly introduced. The project tried primarily to generate data on the impact of chemical composition, i.e. data useful when selecting the alloy best suited to a given purpose, and to gather sufficient body of information on the alloys' structural stability, their major mechanical properties and the property degradation through long-term heat exposure. In this way the study attempted to develop a reliable database for designing the castings and introducing them into the engineering practice.

Key words: nickel-based superalloys, research into mechanical properties, glass industry

1. Introduction

The research aimed to study the issues of structure-related processes occurring at high temperatures, and to reveal the relation between structure and mechanical properties in the superalloys being newly introduced. The project tried primarily to generate data on the impact of chemical composition, i.e. data useful when selecting the alloy best suited to a given purpose, and to gather sufficient body of information on the alloys' structural stability, their major mechanical properties and the property degradation through long-term heat exposure. In this way the study attempted to develop a reliable database for designing the castings and introducing them into the engineering practice.

This comprehensive research was motivated by a desire to master the process of precise casting of a part identified as a "**shredder head**"; the head is used for breaking melted glass into fine fibers to be later employed as insulating material. The melted glass, while being broken into the fibers, is heated to approx. 1000 °C to 1050 °C and the head rotates at approx. 2200 rpms.

2. Materials & methods of their processing

The tests relied on nickel-based superalloys designated 141, 145, 141H, 141I and 2.4879. For the chemical composition of the alloys see Table I. The superalloys were cast into sample parts suitable to study structure, to measure mechanical values, and to test creep properties.

Table I Chemical composition of alloys in %wt.

	145	2.4879	141	141H	141I
C	0.30–0.35	0.35-0.50	0.30-0.40	0.27	0.34
Mn	0.14-0.16	max.1.50	0.85-0.90	0.22	0.58
Si	1.05-1.15	0.50-2.00	0.95-1.10	0.36	0.55
Cr	32.0-34.0	27.0-30.0	23.0-25.0	27.78	26.87
W	7.0-8.0	4.00-5.50	4.50-5.50	4.02	4.94
Co	-	-	max.0.06	3.07	4.47
Nb	-	-	max.0.10	1.84	0.99
Ta	0.80-0.95	-	-	-	0.93
Zr	0.80-1.60	-	-	-	-
P	max.0.015	max.0.035	max.0.019	0.004	0.004
S	max.0.015	max.0.030	max.0.009	0.004	0.006
Ni	balance	47.0-50.0	53.0-55.0	balance	balance
Fe	max.0.10	balance	balance	8.72	7.97

3. Evaluation of results

The study has generated information on the behavior of these materials within the temperature bracket of < 20; 1100 > °C; the information can be instrumental in designing parts expected to operate at high temperatures.

The alloys were tested as-cast and their microstructure and mechanical properties were assessed. Figures 1 and 2 describe the ultimate strength and the ultimate yield, respectively, versus temperature. The resulting curves developed for the tested alloys bear a close resemblance. As expected, the lowest high-temperature strength was observed in alloy 141, while the highest figure was obtained in alloy 145. With their chemical composition modified the 141 I and 141 H alloys demonstrated a slight improvement in strength at high temperatures. The 2.4879 alloy featured properties virtually identical to those of the model alloys. Generally, nevertheless, the differences in strength properties were not substantial. The ductility appears to be best in alloy 141. As regards the balance between the strength and yield properties, good figures were obtained from alloy 141H, while the best were offered by alloy 141I. When compared to alloy 141, the advantageous properties of alloy 2.4879 are somewhat deteriorated as follows from the lower values of ductility found at low temperatures.

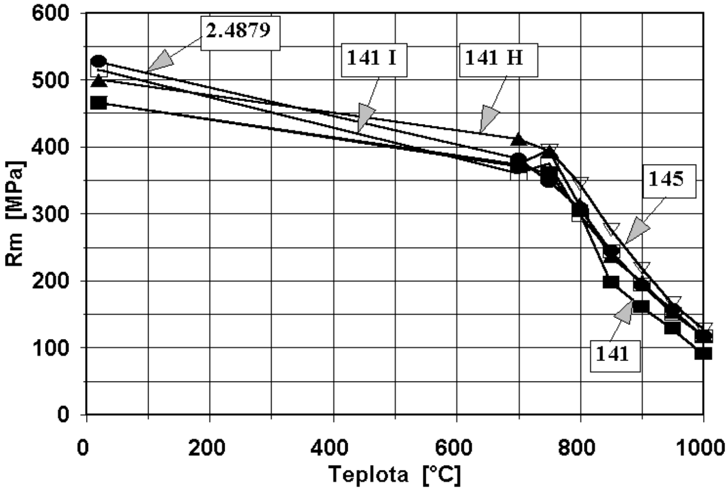

Fig.1 Ultimate strength versus temperature

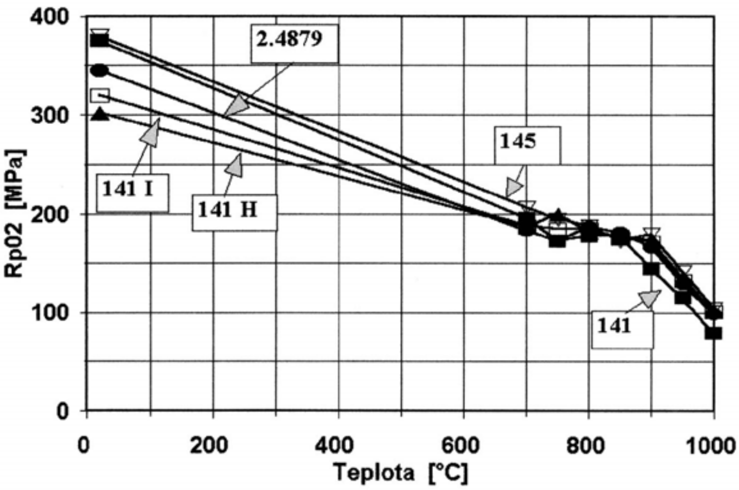

Fig.2 Ultimate yield versus temperature

The alloys being studied demonstrated a marked rise in yield properties at temperatures above 700°C. At lower temperatures the ductility remained low (Figure 3), as is particularly true of alloy 145. It can be concluded that differences in alloying affect primarily the yield properties. The strength differences found within the studied temperature range were just minor.

For all tested alloys the notch toughness versus temperature was also investigated. As follows from the comparison of temperature-related figures of notch toughness, the lowest values were found in alloy 145 (Figure 4). The other four model alloys, as cast, also demonstrated low notch toughness, but the values were high enough to be appraised as acceptable.

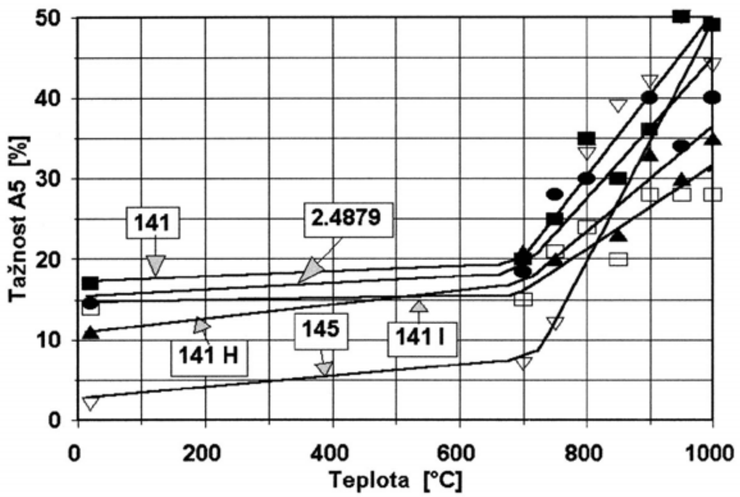

Fig.3 Ductility versus temperature

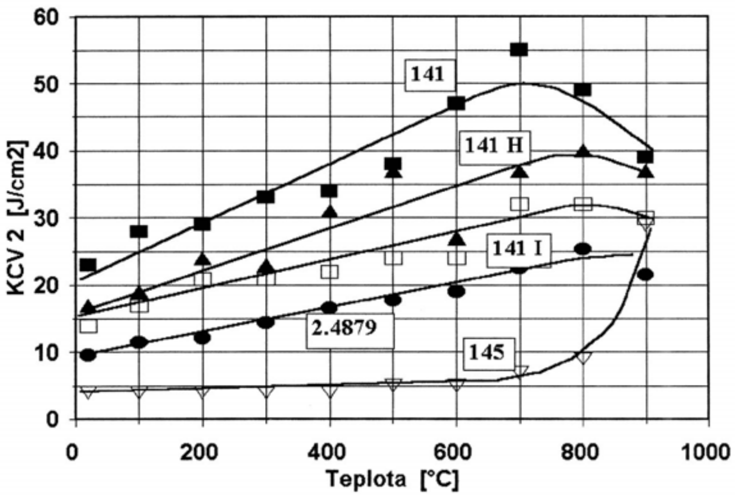

Fig.4 Notch toughness versus temperature

Changes in mechanical properties of alloys induced by long-term annealing

The structural changes were observed at temperatures 900°C and 1000°C after the dwell times of 5, 10, 50, 100, 500 and 1000 hours, and at the temperature of 1100°C after the dwell times of 1, 2, 5, 8, 50 and 100 hours. All metalographic samples were treated to the Vickers HV10 hardness testing. Each sample underwent 5 measurements and the mean hardness value was calculated. Figures 5 to 9 plot the changes in hardness of the individual alloys against the time of their annealing. During the initial 5 hours of annealing the hardness of alloy 141 increased by roughly 30 HV; the result is attributable to the precipitation of carbides in the base matter. After, the hardening effect persisted unchanged for the full time of annealing. In alloy 145 the hardness proved virtually unaffected by the temperature and annealing time. A slight rise in hardness was induced only by σ phase precipitation occurring after long-time annealing at 900°C. In alloys 141 H, 141 I and 2.4879 the hardening effect was minor as well, and the hardness increment stayed correspondingly low.

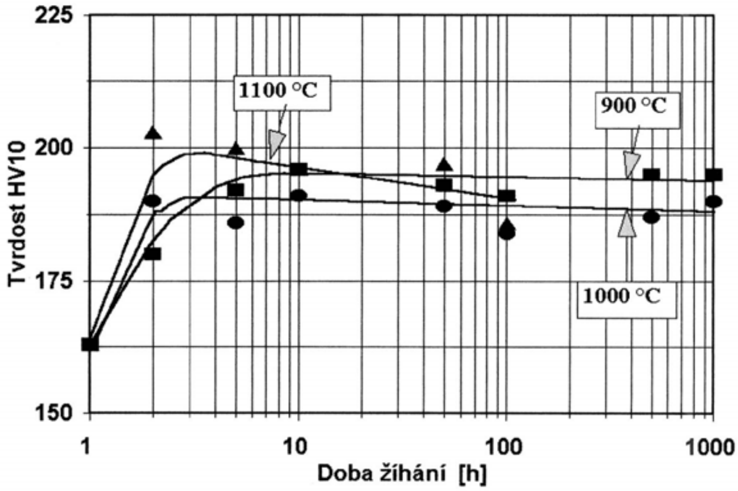

Fig.5 Hardness of alloy 141 versus annealing time

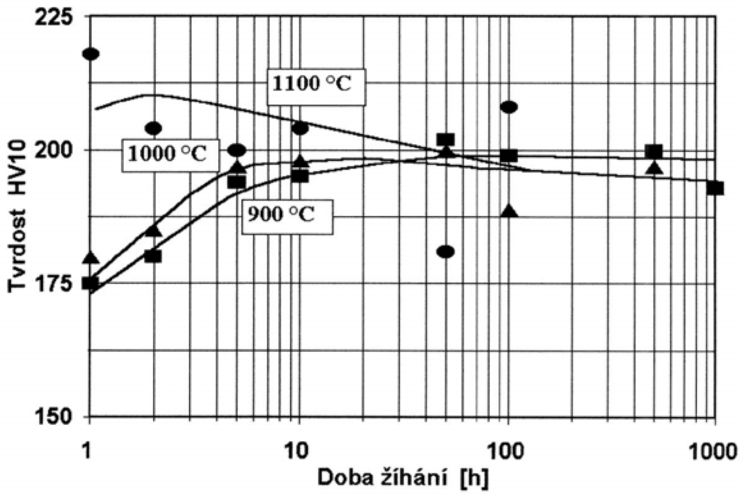

Fig.6 Hardness of alloy 141I versus annealing time

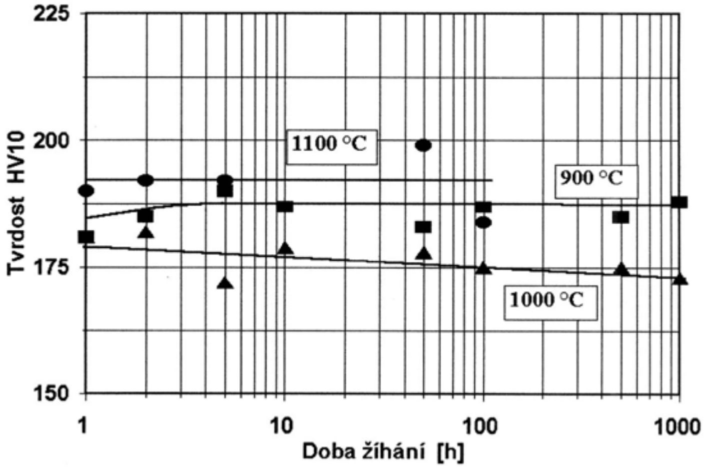

Fig.7 Hardness of alloy 141H versus annealing time

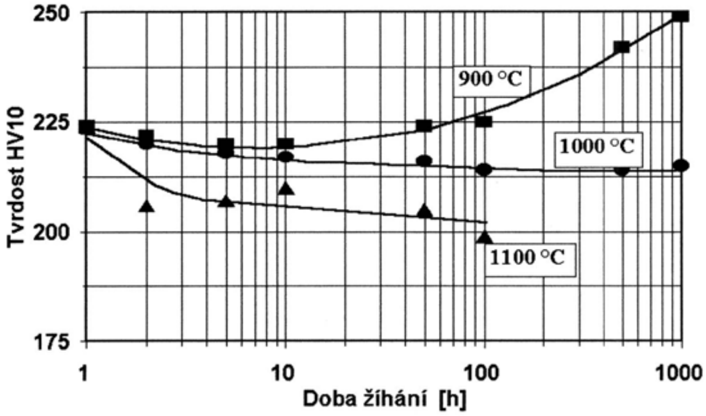

Fig.8 Hardness of alloy 145 versus annealing time

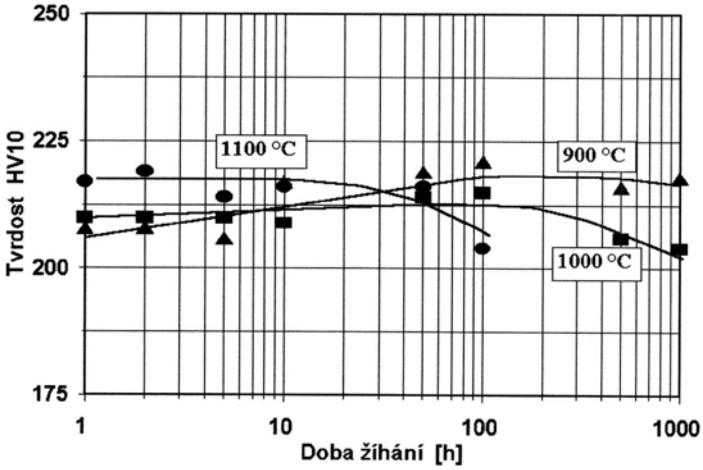

Fig.9 Hardness of alloy 2.4879 versus annealing time

Further, the strength values were examined after annealing at 900°C for the periods of 5 hours and 500 hours. The most significant increase in strength due to annealing was observed in alloy 141. The other alloys exhibited smaller figures of strengthening. Alloy 145, when annealed for 500 hours at 900°C, demonstrated moderate rise in strength caused by the precipitation of the sigma phase. An analogous development of values was experienced in the examined alloys also as regards the changes in the ultimate yield.

Long-time annealing influenced the ductility values, too. Except for alloys 141 H and 145, all the remaining alloys demonstrated a mild drop in ductility when annealed at 900°C. In alloy 145 the overall ductility values were very low and the process of annealing left them virtually intact. The ductility drop was most probably linked to the secondary hardening of the alloys.

Another property measured after long-time annealing at 900°C was the notch toughness. This property was affected by annealing in a manner similar to the manner of influencing ductility. The notch toughness slightly decreased due to hardening induced by the secondary carbide precipitation. The most marked decrease was observed in alloys 141 and 2.4879, where the precipitation hardening was also strongest. The experienced trend of changes in notch toughness was the same at all testing temperatures.

4. Conclusion

The comparative results of mechanical properties of the alloys being examined (1 through 7) confirmed that these types of nickel alloys offer very favorable strength properties at temperatures exceeding 900°C. The examined alloys undergo hardening due mainly to primary carbide precipitation at the grain boundaries of the casting structure, where the carbides form a tough skeleton. That is the reason why their yield properties, ductility and notch toughness are low, but for the practical engineering purposes still acceptable. Within the range of envisaged operation temperatures, i.e. over 800 °C, the yield properties of all model alloys are very good.

At present, the *První brněnská strojírna Velká Bíteš* works is capable of delivering castings made of these alloys up to the weight of 20 kg (Figure 10).

Fig.10 Shredder head made of superalloy 141

Acknowledgement

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Literature

[1] Kudrman, J., Podhorná, B., Čmakal, J.: Study of properties and microstructure. Report No.: 927, Škoda - ÚJP Praha, 2000

[2] Sklenička, V., Kuchařová, K., Daněk, R.: Acquiring set of data on the major creep properties of some selected cast nickel alloys. Interim Report on Project Solution, ÚFM AV ČR Brno, 2000

[3] Hrbáček, K., Joch, A., Svoboda, O., Hrbáček, K., Božek, J.: Development Center for cast nickel superalloys to be used in extreme conditions at high temperatures. Research Report, PBS VB, Velká Bíteš, 2000

[4] Siegl, J.: Fractographical atlas of cast nickel alloys - 141, 141H, 141 I, 145, 2:4879. Research Report, V- KMAT- 515/01, ČVUT Praha, 2001

[5] Dobrovská, J., Stránský, K., Dobrovská, V., Rek, A., Pawliczek, A., Pokludová, J.: Heterogeneity of a nickel-based superalloy. Research Report MP 612014, VŠB – TU Ostrava, 2001

[6] Kudrman, J., Podhorná, B., Čmakal, J.: Cast alloys of the Ni – Cr – W – C types & the Dameron alloy. Report No.: 1002, UJP Praha, 2002

[7] Musil, V., Hrbáček, K., Burian, P., Joch, A., Hrbáček, K.ml.: Development Center for cast nickel superalloys to be used in extreme conditions at high temperatures. Research Report, PBS VB, Velká Bíteš, 2002