COMPARISON OF AN AIRCRAFT UNDERCARRIAGE V-ROL N STEEL WITH A SUBSTITUTING VIP P-ROL N STEEL CONSIDERING COMPOSITION, MICROSTRUCTURE, MECHANICAL AND FATIGUE PROPERTIES

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Abstract

In the past, V-ROL N steel, produced at Poldi Kladno, was used for many years for a manufacture of aircraft undercarriages, particularly for quite famous small aircraft L 410. As a result of privatisation process in the nineties and other circumstances, the V-ROL N steel, known by its very good or even excellent properties, has not been more available. Within the recent Czech research and development project MOSTA aimed at modernisation of the L 410 Turbolet aircraft, a substitution of materials previously used became an issue. The paper contains results of an extensive experimental programme aimed at comparison of the V-ROL N steel used in the past, still available for research purposes, with another steel of a similar type, VIP P-ROL N steel, manufactured in Czech Republic. The results show that in spite of that some differences in chemical composition and some mechanical properties exist, the substituting steel has encouraging properties. A specific attention is paid to fatigue resistance, where not only comparative fatigue S-N curves are presented, but also some aspects of fatigue damaging process and mechanisms are discussed..

Keywords: Aircraft undercarriage steel, fatigue resistance, fatigue damage mechanisms

1. INTRODUCTION

Landing gears are essential and heavy loaded parts of aircraft structures. Though it may seem that their safety and reliability are not so critical as those of other parts of aircraft structures, because their failure can occur just on the earth - on the runway during take-off or landing, failure at high landing and take-off speeds can cause serious crashes with a high number of fatal injuries or at least high material losses due to consequent damage of the aircraft as a whole. One of numerous examples is a recent crash of an Airbus A 320 aircraft due to fracture of the front landing gear during take-off, which occurred in Philadelphia on 14 March this year, fortunately without any serious injuries, just with a serious damage to the aircraft - **Fig. 1** [1]. Therefore, landing gears also belong to components, where proofs of safety and reliability at service conditions according to strict aircraft criteria are claimed.

Fig. 1 Airbus A 320 crash due to break of front landing gear during take-off in March 2014. Source Novinkv.cz

Loading of the landing gear components during take-off and particularly landing is very severe. Therefore, the components, more exactly its material must have besides high strength also an excellent resistance to dynamic and impact loads and resistance to repeated dynamic loading - to fatigue. That is why high strength steels with a high fracture toughness and fatigue resistance are being used for manufacture of these components. Considering this combination of properties, the most suitable are low- or medium alloy steel of either of Cr-Ni or Ni-Cr-Mo or Ni-Si-Cr-Mo-V types [2]. Typical examples of landing gear steels used in the world are AISI 4330, AISI 4340 or AISI 300M, the latter being of the best quality [3].

Though fatigue resistance of the landing gear material is one of the most important issues, there is just a small number of works dealing with fatigue in the literature. Much higher amount of works is concern mechanical properties or fracture toughness of landing gear steels, often discussing effects of detailed parameters of heat treatment and microstructure on such properties [4 - 6]. It follows from these works that mechanical properties and fracture toughness can be significantly affected by microstructure details like residual austenite with positive effects or, on the contrary, undissolved carbides and sulphide inclusions with negative effects. Carbides and sulphide inclusions act as crack nuclei and can reduce fracture toughness even by 50 %. Similar damaging mechanisms can be expected in case of fatigue loading, too. If fatigue properties are presented in the literature, then mostly in connection with technologies used, like surface treatment including shot peening [7, 8].

In Czech Republic, an aircraft company Aicraft Industries a.s., in the past known as LET Kunovice, have been successfully manufacturing a small passenger aircraft L 410 already for many years. Landing gears of this aircraft have been manufactured from an Ni-Cr-Mn-Si steel L-ROL N, more exactly from its vacuum melted version V-ROL N, produced at Poldi Kladno. This material was known by its very good or even excellent properties. However, as a result of privatisation process in the nineties and other circumstances, it has no more been available. Consequently the steel has to be substituted by another material. A good occasion occurred during the implementation of a research and development project FR-TI2/557 - MOSTA of the Czech programme TIP. The project has been aimed at modernization of the L 410 aircraft with the target to increase its service effectiveness and economy.

The paper contains results of an extensive experimental programme aimed at comparison of the V-ROL N steel previously used, still available for research purposes, with another steel of a similar type, VIP P-ROL N steel, manufactured in Czech Republic by a new company. An attention was paid to chemical composition, mechanical properties and fatigue resistance. Results of fatigue S-N curves are presented and some aspects of fatigue damaging process and mechanisms are discussed.

2. EXPERIMENTAL PROGRAMME

As already mentioned, experimental programme was performed on two very similar types of steel, (i) V-ROL N steel used in the past and (ii) new steel VIP P-ROL N, which should substitute the previous one no more available. The main difference between the steels concerns the manufacture process, when the new steel is melted under slag whilst the previous one, V-ROL N was melted just in vacuum.

Experimental programme was aimed at an evaluation of the following characteristics:

- chemical composition, microstructure and material purity,
- basic mechanical properties,
- resistance to brittle fracture - notch toughness,
- fatigue resistance and
- mechanisms of fatigue crack initiation using fractographical analysis.

Chemical composition was evaluated using computer controlled optical-emission device SPECTROMAXX. Static strength was estimated from several measurements of HV 30 hardness performed directly on selected specimens dedicated for fatigue tests and strength was then calculated using valid standard methods [9]. Though evaluation of material strength by this method is not so exact like static strength test, an advantage of this approach consisted in obtaining data directly from specimens tested later in fatigue. Concerning notch toughness, two characteristics were evaluated, namely $KU3_2$ and $KCU3_2$. Tests were performed on Charpy impact test machine PSWO 30 with maximum impact power 300 J.

Fatigue tests were carried out in axial tension load on AMSLER resonance machine equipped with Zwick control electronics. Tests were performed at different load ranges to obtain the whole S-N curve including fatigue limit. Load asymmetry was R = 0.05, load frequency around 80 Hz. Specimens with circular cross section were used with the diameter in gauge section originally 6 mm, which had to be later reduced to 5 mm due to an occurrence of cracking in attaching threads of M12 type.

After finishing fatigue tests, selected specimens, namely those with particularly low and high fatigue lives in comparison with mean value of regression line, were further examined using scanning electron microscopy - microscope Zeiss. Fractographical analysis was performed to gain knowledge particularly on fatigue crack initiation mechanisms.

3. RESULTS AND DISCUSSION

Results of chemical analysis in terms of the content of allying elements of the V-ROL N and VIP P-ROL N steels are shown in diagram in **Fig. 2**, together with typical average values of other two most similar AISI low alloy steel generally worldwide used for the manufacture of landing gears - AISI 4330 and AISI 4340 [10, 11]. Results of material strength calculated from hardness values HV 30, measured on four different randomly selected fatigue specimens (before fatigue testing) are shown in **Fig. 3**.

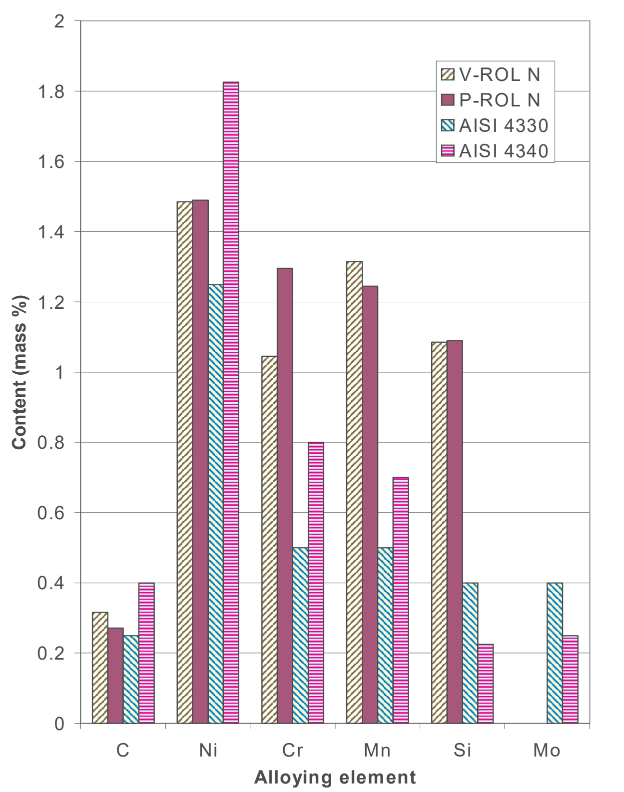


Fig. 2 Chemical composition of V-ROL N and VIP P-ROLN steels in comparison with AISI 4330 and 4340

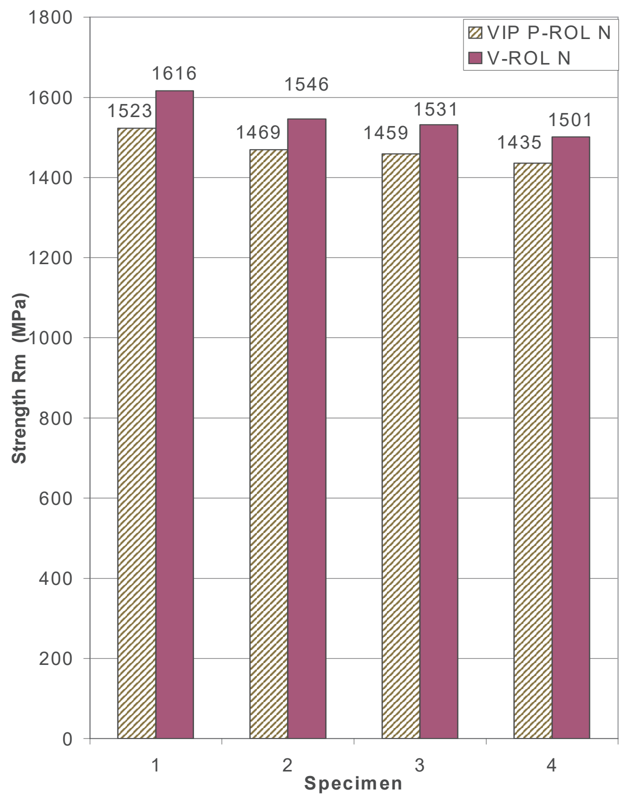


Fig. 3 Comparison of strength measured in different specimens of V-ROL N and VIP P-ROLN steels

It follows from **Fig. 2** that the alloying element content in the investigated steels is very similar, almost identical with the exception of chromium, which is approximately by 0.25 weight percent higher in the VIP P-ROL N steel. The diagram also clearly shows that the two AISI low alloy landing gear steels are similar, but definitely not identical. Both have quite significantly lower content of Cr, Mn and Si, but they contain Mo. The content of Ni is higher in AISI 4340 and lower in 4330 version.

Concerning strength, the values of VIP P-ROL N are slightly lower in comparison with V-ROL N, but the difference of the average strength is no more than 5 %. Note that in this stage of investigation, the VIP P-ROL N was intentionally heat treated to the lowest strength limit accepted by aircraft design standards. Scatter of strength values is comparable in both steels, in VIP P-ROL N is slightly lower. Average strength is 1549 MPa and 1472 MPa for V-ROL N and VIP P-ROL N steels, respectively.

Microstructure of both steels was almost identical - homogeneous martensite with single islands of retained austenite. Purity of both steels was high. The evaluation according to ČSN EN ISO standard is as follows: sulphides - stage 1.5 in both steels, oxides - stage D 1.0 and 0.5 in V-ROL N and VIP P-ROL N steels, respectively. Microstructure is documented in **Figs. 4** and **5**.

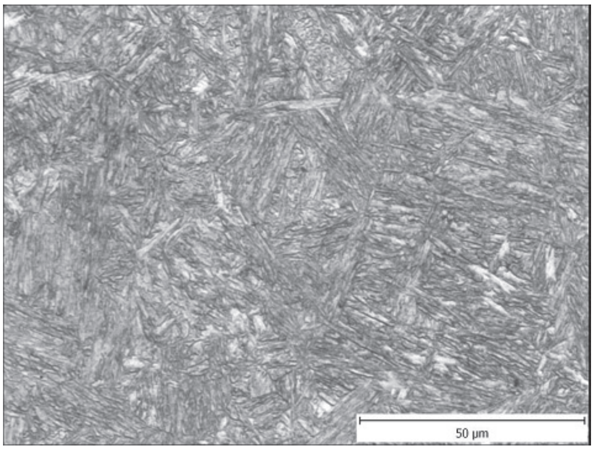


Fig. 4 Martensitic microstructure of V-ROL N steel

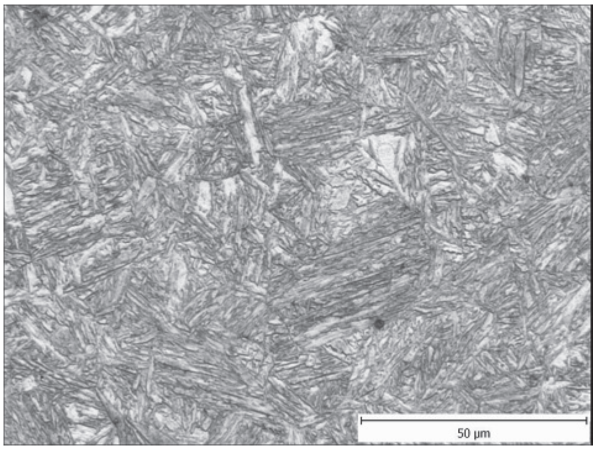


Fig. 5 Martensitic microstructure of VIP P-ROL N

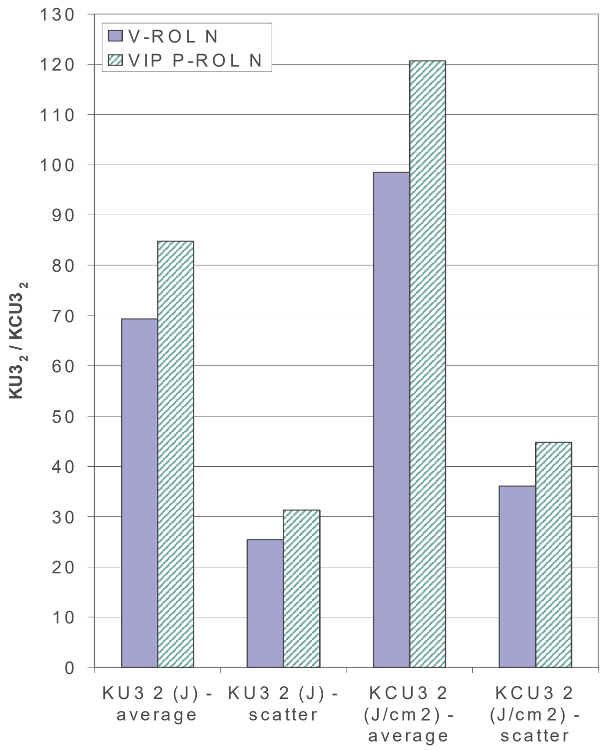
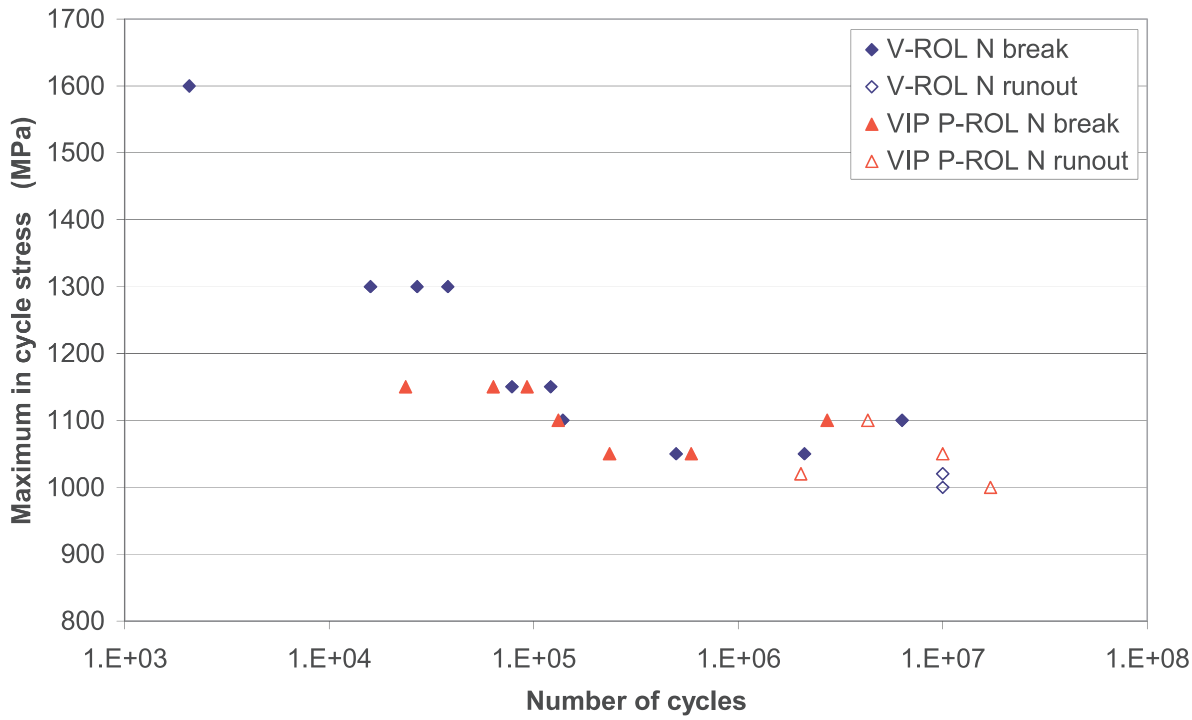


Fig. 6 Charpy notch toughness of the steels

As regards resistance to impact loading and brittle cracking evaluated in terms of Charpy notch toughness, it is the only characteristics where differences between the two steels can be considered as fairly significant. Values of VIP P-ROL N steels are somewhat higher than those of V-ROL steel - **Fig. 6**. This may be connected with the higher content of Cr in VIP P-ROL N, as this element in combination with Ni usually increases toughness of low alloy steels [2]. However, the scatter is also higher indicating somewhat lower homogeneity of VIP P-ROL N. Differences of notch toughness of the steels will be further discussed in connection with results of fatigue tests.

Results of fatigue tests are shown in **Fig. 7**. At first sight, the results are very similar, which is a good conclusion from the point of view of the intended material substitution. In both steels,



fatigue limit is slightly below 1050 MPa, which is a good and expected value. However, if the results are analysed more in detail, some differences yet exist.

Fig. 6 Results of fatigue tests of V-ROL N and VIP P-ROL N steels

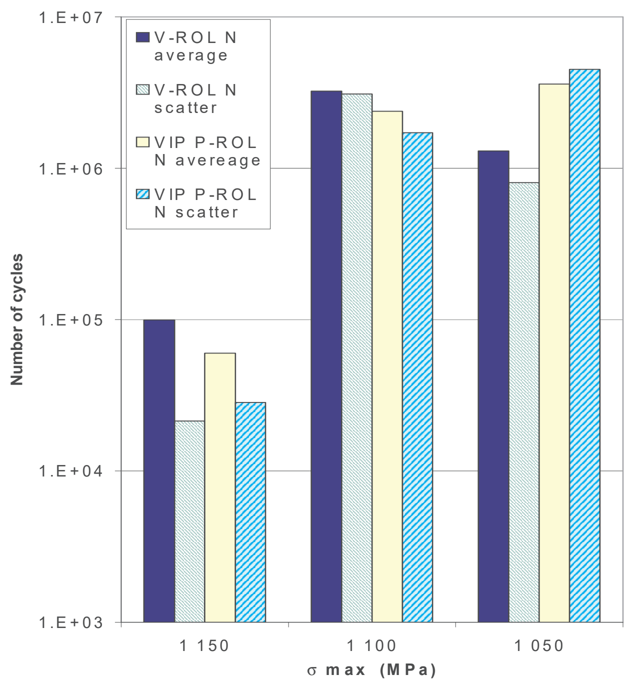


Fig. 7 Fatigue life and scatter evaluated for three different load levels σ_{max}

The results in **Fig. 6** indicate slightly better fatigue resistance of VIP P-ROL N steel at loads near fatigue limit, but slightly worse life at higher amplitudes. Also scatter of fatigue life of VIP P-ROL N near fatigue limit is higher. Note that there is even no failure at load level 1100 MPa, but quite early breaks at 1050 MPa.

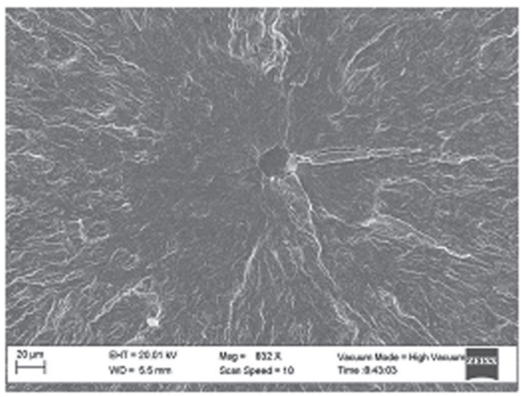


Fig. 8 Example of subsurface fatigue crack initiation on 20 μm large inclusion

Fractographical analysis enabled to explain the fact, while fatigue strength of VIP P-ROL N steel is good, even slightly better in comparison with V-ROL N steel, but there is a higher scatter and fairly premature breaks can be observed in some cases. Fatigue crack initiation in VIP P-ROL N namely occurred on inclusions, even quite large, more than 40 μm. Though the metallographic purity was evaluated as high, there were rare, but yet existing single inclusions. Their occurrence was quite low and so, several subsurface crack initiations were observed, showing that the predominant fatigue mechanism was affected rather by resistance against growth of short crack-like defects than crack initiation on smooth surface.

The occurrence of rare inclusions in VIP P-ROL N steel is in consistency also with the higher scatter of Charpy notch toughness, as not only fatigue cracks, but also cracks under monotonic loading can be initiated at inclusions, as already mentioned in the literature [4].

CONCLUSIONS

A comprehensive experimental programme was carried out with the aim to compare fatigue resistance and other properties of low alloy aircraft landing gear steels V-ROL N, no more available, and VIP P-ROL N steel, which should substitute the former one. The main results can be summarised as follows:

- Chemical composition of the steels was almost identical with the exception of chromium, which content was slightly higher in VIP P-ROL N steel.
- Microstructure was homogeneous of martensitic type in both steels, the purity was quite high.
- Notch impact toughness was good in both steels, but in VIP P-ROL N evidently better. On the other hand, there was a higher scatter of values in this steel.
- Fatigue resistance was also comparable. However, VIP P-ROL N indicated slightly better fatigue strength near fatigue limit, but also higher scatter. These results were explained by an occurrence of quite rare, but yet existing inclusions, which initiated fatigue cracking.

A general conclusion is that the investigated VIP P-ROL N is a suitable and acceptable substitution of V-ROL steel, in some aspects even better. However, a particular attention has to be paid to the matallographic purity and any absence of fairly large inclusions, even quite rare, has to be avoided.

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