Particle Analyses in Modified Nickel-base Alloys by Synchrotron Radiation

C. Siemers[1], K.Saksl[2], Z. Spotz[2], S. Hagemann[1], J. Laukart[1] and P. Rokicki[2]

[1]*Institut für Werkstoffe, Technische Universität Braunschweig, Langer Kamp 8, 38106 Braunschweig, Germany*

[2]*Institute for Materials Research, Slovak Academy of Sciences, Watsonova 47, 04353 Kosice, Slovakia*

Nickel-base superalloys are normally used in high-temperature applications whenever steels (due to drop in mechanical properties at elevated temperature) or titanium alloys (due to insufficient oxidation resistance above 550°C) cannot be applied anymore. In aerospace engine applications or in stationary gas turbines, excellent mechanical properties are needed at temperatures above 600°C in combination with corrosion and oxidation resistance [1].

Due to its excellent corrosion resistance, the class of Ni-Cr-Mo alloys like Alloy 625 (chemical composition in wt% Ni: bal, Cr: 20 – 23%; Fe: <5%; Si: <0,5%; Mn <0.5%; Mo 8 – 10%; Ti <0.4%; Co <1%; Nb + Ta: 3.15 – 4.15%; Al <0.4%) is, therefore, not only applied in stationary gas turbines as sealing material or for exhaust systems, but is also used in low-temperature applications in the oil or gas industry wherever the corrosion resistance of steels in liquid media is not sufficient anymore.

During the component manufacturing of related Alloy 625 products in any application, up to 50% of forged semi-finished parts have to be removed by different machining operations. If the finished parts were assembled from prefabricated components, welding or brazing would be involved, which might cause microstructural transformations leading to increased notch-sensitivity or to the formation of δ-phase. Therefore, machining from a single workpiece is preferred. Due to the high strength and toughness of Alloy 625 only low cutting speeds can be applied during metal cutting operations as otherwise poor surface quality and enhanced tool wear is observed. In addition, the cutting process has to be interrupted as often as it is necessary to remove the long chips from the process zone. Automation especially of turning or drilling operations is, therefore, impossible. The following suggestions are given for machining of Alloy 625: turning operations, cutting speed < 80 m/min, drilling operations, cutting speed between 3 m/min and 5 m/min.

In order to improve the machinability of Alloy 625, 0.5 wt% (named Alloy 625 FM-05), 1 wt% (named Alloy 625 FM-1) and 2wt% (named Alloy 625 FM-2) of silver (Ag) have been added. As starting materials for the alloy production, the commercially available material Alloy 625 [2] and pure Ag (purity 99.99%) have been used. The standard Alloy 625 has been investigated as a reference material. All alloys (including the reference alloy Alloy 625) were fabricated by plasma arc melting in a laboratory PB-CHM (plasma beam cold hearth melting) furnace of a capacity of about 500 g. After melting, turning and two times remelting (to ensure sufficient homogeneity of the alloys) the material has been poured into a water cooled copper crucible (fast cooling). The resulting bars of diameter 13 mm and length about 90 mm have been investigated either directly in the as-cast state or have been subjected to two different heat treatments, namely (1) 800°C / 4 h / air cool, the "stress relief anneal" and (2) 1038°C / 1 h / water quench, the "low temperature solution anneal".

According to the Ni-Ag binary phase diagram, the solvability of Ag in Ni is negligible at room temperature, whereas complete solvability exists in the liquid state. During the solidification of the Ag-containing alloys, the nickel matrix crystallises first and the remaining liquid phase is enriched in Ag. Finally, Ag-rich particles should form in the interdendritic areas and on the grain boundaries. The microstructure of the silver containing alloys consists of a nickel matrix containing γ', γ'' or δ-phase (depending on the heat treatment performed) and additional particles having a globular shape, see Fig. 1, left. The particle size lies between 1 µm and 10 µm, see Fig. 1, right. The particles are homogenously distributed in the alloy.

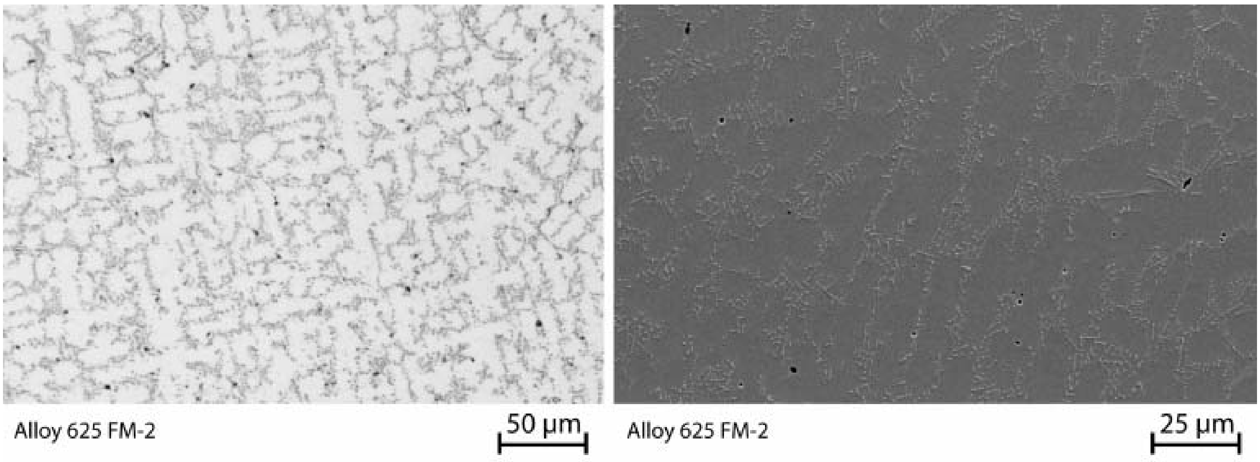

Figure 1: Typical microstructure of Alloy 625 containing 2 wt% Ag subjected to the stress relief heat treatment. Left: Optical microscopic image; besides the nickel matrix (bright), δ-phase is observed (grey); in addition, Ag-rich particles (black spots) are visible. Right: SEM-image of Alloy 625 FM-2, the Ag particles are homogeneously distributed in the matrix material.

As the nature of the particles is of crucial importance for improved machinability they have been investigated in hard X-ray experiments at BW5, HASYLAB, DESY, as the volume fraction is too low for standard X-ray investigations and information from the bulk material is needed. The particles in all Ag-containing alloys consist of elementary silver; the related lattice parameter of the fcc Ag cell has been measured to $a \approx 0.4085$ nm (three peaks). Intermetallic compounds have neither been found in the as-cast state nor after the several heat treatments performed [3].

The machinability of the Ag-containing alloys has been investigated in straight turning experiments. The cutting speed has been varied between 20 m/min (continuous chip formation in the standard material) and 80 m/min (segmented chip formation in the standard material). Two cutting depths of 0.5 mm and 1 mm were used and the feed rate has been fixed to 0.1 mm/rd. The rake angle has been varied from 0° (as used in the orthogonal cutting experiments) to 25° (standard in metal cutting of Alloy 625 in industry). During turning of the standard alloy Alloy 625, long chips (length of more than 1000 mm) have been produced independent of the cutting conditions applied. The Ag-containing alloys, on the other hand, formed short-breaking or fragmented chips if a minimum cutting speed of 60 m/min (in case of 0.5 wt% Ag) or 40 m/min (in case of 1 wt% Ag or 2 wt% Ag) has been used [4]. All chips could be manually fragmented. The shortest chips were produced while machining Alloy 625 FM-2. In any case, the cutting speed needed for the formation of short breaking chips was lower than the cutting speed used in industrial machining. Therefore, the beneficial effects of the modified alloys (i.e. automation of cutting operations) could be exploited during industrial component manufacturing. In addition, it can be expected that tool wear decreases due to the shorter contact length between rake face of the tool and chip leading to lower temperatures at the tool tip.

References

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