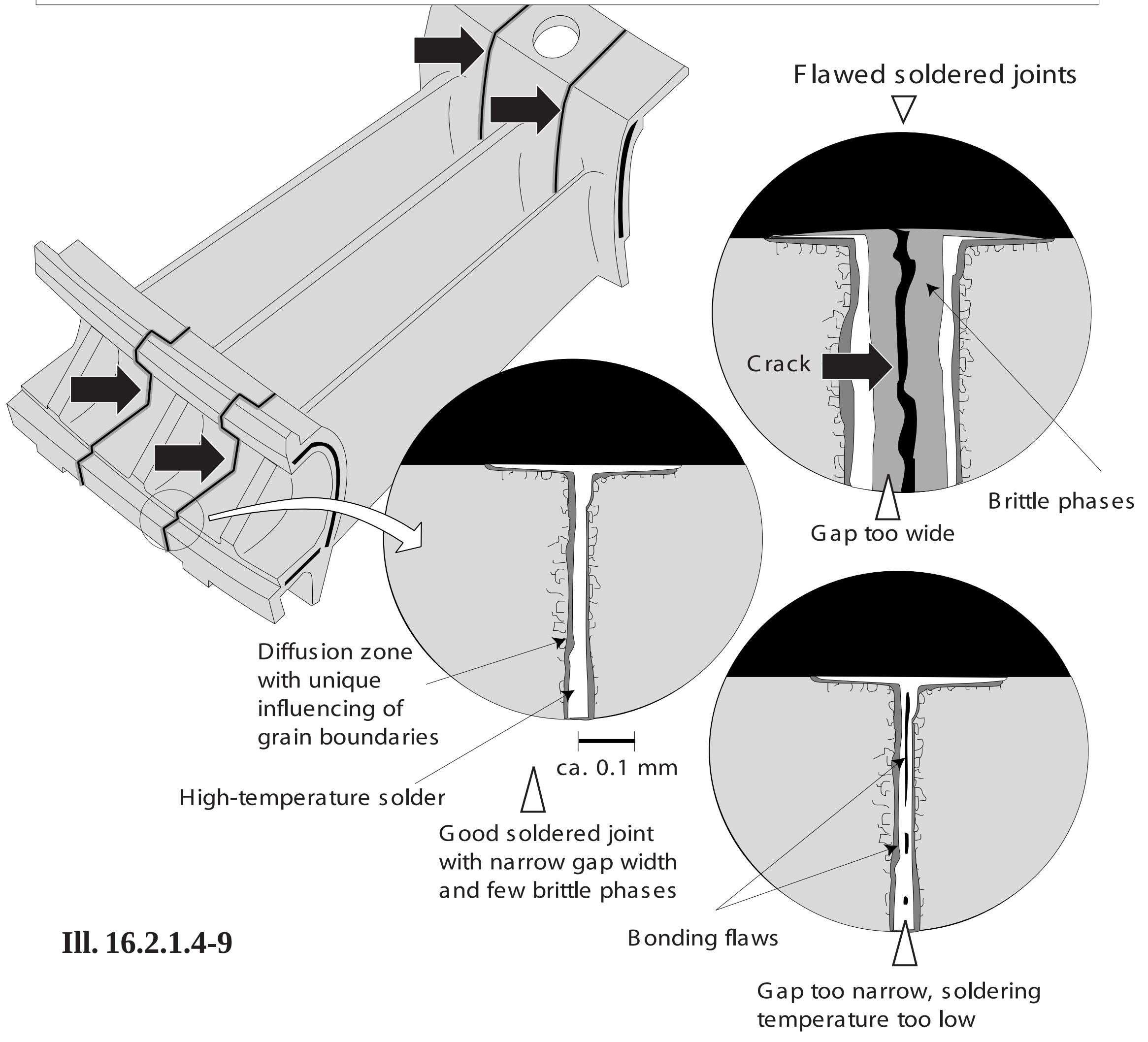
The properties of high-temperature soldered joints are especially dependent on the soldering gap.



Ill. 16.2.1.4-9

Illustration 16.2.1.4-9: *In the depicted case, soldering is used to* ***join individual turbine blades to a larger segment*** *(top diagram). High seam quality with a minimum of hard material phases depends on optimal gap width (left detail). If the gap is too wide, it will result in brittle phases that can cause premature cracking during operation (top detail). On the other hand, if the gap is too narrow it will result in bonding flaws (bottom detail).*

At gap widths around 25 µm, nickel-based alloys form hard material phases *(Ref. 16.2.1.4-20) that have a negative effect on the ductility and strength of the joint. The fracture toughness of these solders is in the range of 1% or 2% (Ref. 16.2.1.4-6). The hard phases in the soldering gap can cause* ***large fluctuations of the modulus of elasticity and strength.*** *Their distribution in the solder seam has a decisive influence on* ***dynamic strength****, especially* ***thermal fatigue.***

Subsequent diffusion annealing can break down the embrittlement. During the annealing, the concentrations are balanced with the base material. Melting-point-reducing additives such as B, Si, and P are diffused. The ***soldering gap should be smaller than 50 µm*** *in order to keep the diffusion paths sufficiently short. In the middle of the seam, a softer, ductile, diffusion-free zone is created. Micro-ductile forced*

cracks spread through this zone. However, complete dissolution of the hard phases cannot be expected. Therefore, a soldering joint will always result in a certain strength loss. Because these weak points are found in the entire solder cross-section, dynamic fatigue cracks in soldering joints can also spread from the inside (Ref. 16.2.1.4-4).
The evaporation of the solder additives also raises the melting point of the solder (Ill. 16.2.1.4-4). This becomes apparent during any repair soldering.

Strength behavior of soldered joints at temperature:

The behavior of solders under long-term heating without significant mechanical loads.

*High-temperature soldered joints usually tolerate **operating temperatures up to about 800 °C and short-time overtemperatures of up to 1100 °C.** The Cr content of the solder is especially important for its strength and oxidation resistance. Phosphorus and manganese solders, on the other hand, only have low oxidation resistance at very high strengths.*

*The different compositions of the solder and base material result in **concentration gradients of the alloy components**, which promotes the diffusion of single elements.*

*Diffusion tends to act in the direction of lower concentrations, but in exceptional cases it can also act in the reverse direction ("up hill"). Diffusion not only changes the structure of the base material in the contact area of the solder, but also changes its strength properties (embrittlement, reduction of creep strength). **This means that after longer heating times, entirely different bonding characteristics will be present.***

High-temperature strength of soldered joints *(short-time loads at temperature): Normally, increasing temperatures will be accompanied by a steady decrease in strength.*

*This decrease usually begins earlier than in the base material, although the bond strength is related to the strength of the base material. The greater the base material strength, the better the bond strength with the same solder (Ill. 16.2.1.4-3). However, sometimes a strength maximum can be observed in a limited range of increased temperatures. This is due to the corresponding increase in hardness in the solder caused by the formation of a special structure. In high-temperature solders made from closely related materials, which only contains small amounts of melting-point-lowering additives, it is possible that **the diffusion of these additives will cause the strength of the joint to increase** as the operating time increases. The creep behavior of soldered joints is similar to that of the base materials (Volume 3, Ill. 12.5-3): initially, relatively fast creep occurs, and its speed decreases. Next, creep continues at a relatively low and even rate, accelerating again towards the end of the part life. Therefore, like the short-term behavior, the creep behavior of soldered joints depends not only on the solder, but also on the strength of the joined base materials. Often, above a certain temperature, an alloy component will diffuse from the solder into the base material/ solder contact surface. During this process, pores will be created, especially on the contact surface. It is not clear how important the Kirkendall effect is in addition to the creep pore formation. The growth of the pores can lead to cracking and fractures. **Above about 700°C** most high-temperature solders only have **minor creep resistance** due to the diffusion processes.*