Literature survey: leaded brass *vs.* unleaded copper alloys (summary)

One of the oldest references to the beneficial effect of lead in brass goes back to 1859. In the *Dictionnaire Universel Théorique et Pratique du Commerce et de la Navigation* one can read on page 942 that unleaded brass greases the rasp, i.e. that it sticks into the interstices of the teeth and hinders their biting: the addition of 2 to 3 % of lead makes that this inconveniency disappears and hardens the alloy. Because practical experience has shown since those days the overall good properties of leaded free machining brass, no real technical or scientific investigations were realized to demonstrate the beneficial role of lead as a minor alloying element. It is only since some twenty years – when the impact of lead on the quality of drinking water started to be questioned – that a few papers can be found in the technical and scientific literature which reports comparative experiments on leaded and unleaded copper wrought and casting alloys. A literature has allowed gathering 26 relevant publications. They focus mainly on "new" alloys containing bismuth, selenium, silicon as alloying substitutes to lead. Even more exotic elements like titanium or graphite were evaluated (Li 2011, Rohatgi, Saigai). A common aspect of all those alloys is that they were developed first of all as substitutes for casting yellow and red brasses. Therefore the first property which was investigated was their ability to be cast followed by the ease to be machined in a finishing step. Obviously the corrosion resistance in drinking water was also tested, because the alloys are aimed to be used predominantly for plumbing devices. On the contrary in the automotive sector only wrought copper alloys are used with a complete different microstructure. Therefore most of the findings are irrelevant for the presently discussed problem.

In the following we will shortly present some of those 27 papers. They are listed in the reference document.

One of the first newer studies about leaded and unleaded free machining α/β-brass was motivated by concerns about the sliding behaviour of unleaded brass (Gane 1981). Indeed, the friction coefficient is reduced by half when 2.9 % of lead is added to brass. The consequence is that the rake face friction in machining is reduced by a factor of five. The beneficial role of lead as machining force reducing lubricant has been shown by various researchers (Klocke 2012 - 1). 3 % of lead in an α-brass outdo 0.5 % in an α/β-brass as a force reducing agent by at least a factor of three – and this rather independently of the temperature in the range 0 to 200 °C (Masounave 2007). Furthermore, like it was noted more than a century ago, lead reduces the adhesion of copper on the cutting tool (Klocke 2012-2). Lead free copper alloys strongly increase the wear of the cutting tool – even if the presence of zinc reduces somewhat this deleterious effect. The consequence is not only a reduction of the life-time of the tool, but first of all a deterioration of the surface quality. This becomes very apparent in a finishing operation with small feed speed and cutting depth. The only way to maintain an acceptable surface quality is to flood with a high pressure jet of lubricant the cutting edge of the tool which has to be coated with polycrystalline diamond – a technology the technical, economic and ecologic justification can be questioned.

A smooth surface finish is mandatory to improve the resistance of copper alloys to corrosion damage like dezincification in a chlorine environment, independently of the lead content (Karpagavalli and Balasubramaniam 2007). Whereas lead seems not to affect the corrosion resistance of brass in comparison to the corrosion inhibitors tin and arsenic, the situation changes in a sulphuric environment (Ismail 2005). The reason is the formation of a lead sulphate layer on the surface which strongly reduces the corrosion rate. The effect is pronounced for lead concentrations above 2.5 %. This confirms elder findings where the samples have been exposed to sulphate environments. Leaded brass behaves also better in Mattson's solution known to initiate easily stress corrosion cracking (You 2002). Lead is also a better corrosion damage inhibitor than bismuth in synthetic tap water (Kwon 2000).

Although these studies have emphasised the beneficial role of lead when machining, friction or corrosion aspects are concerned, it was also made clear that lead deteriorates the mechanical behaviour of brass - nevertheless to a lesser extent than bismuth (Jang 2004). Lead hinders also stud welding (Kerry 1985). Occasionally, a trade-off must be done to optimise the lead content: an example is when both good machining and cold forming capabilities are asked for (Akin 1993).

Some new alloys like silicon containing brass have both better mechanical and corrosion resistance properties. But nowadays such brass alloys are no longer considered as a substitute for leaded free machining brass, but for stainless steel (Hofmann 2005, Wieland 2005, Scharf 2007).

To complete the survey, one should mention the bismuth and selenium containing red brasses, which were developed in the USA and Canada as a substitute of high leaded red brass used predominantly to cast plumbing devices (Sadayappan 2002, Sadayappan 2005). Besides the fact that they are lead-free, they have proven to be inferior in all respects to leaded brass.

Once again, the information gathered from literature has shown that there is no "universal" alloy which can match leaded free machining brass. Thus this alloy has to be considered as an optimal material for specific applications and there is little hope to find ever technical alternatives.

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Literature survey: leaded brass *vs.* unleaded copper alloys (references)

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