Cautionary Tale: Stainless Steel, 100 years old

Stainless steel was invented 100 years ago in Sheffield, and this invention is currently being celebrated in IST's home city of Sheffield, the birthplace of steel. For those interested in the history of this important spring material, then there is an excellent new book written by Sheffield Metallurgist, Dr David Dulieu entitled "Stay Bright" that describes stainless steel from it invention by Harry Brearley to a description of the stainless steel industry today.

In the last cautionary tale the oxide that forms naturally on stainless steel was discussed, and how that oxide confers corrosion resistance. This prompted the idea that the various types of stainless steel should be described. They all have a layer of chromium oxide and so are corrosion resistant, but there are four distinct types of stainless steel, two of which are excellent for spring production, but the other two are not.

Harry Brearley invented stainless steel with 13%Cr (chromium) and 0.25%C (carbon), which becomes corrosion resistant after it has been hardened and tempered to a martensitic microstructure. At first sight this might seem ideal for springs – it is corrosion resistant and has high strength. It is used for knife and surgical instruments, industries for which Sheffield remains famous today. However, martensitic stainless steel has a fatal flaw that makes it a very unlikely choice for making springs, and that is that a trace of corrosion will cause this type of stainless steel to fail by stress corrosion cracking. That is the first moral of this cautionary tale – do not be tempted to use martensitic stainless unless you are certain that its corrosion resistance is good enough.

For springs, we need a stainless steel that will repair its oxide film in the event of slight corrosion before it fails. Stainless steel with 18%Cr and 8%Ni (nickel) has better corrosion resistance than the martensitic type, and does this. It has a microstructure that is austenite, which needs to be cold worked to acquire spring strength. The microstructure is austenite prior to the start of the wire drawing process, but during wire drawing some of the austenite transforms to martensite, and this is what makes this grade slightly magnetic. The predominant microstructure remains austenite though, and this type of stainless steel is the most frequently used for springs everywhere in the world today. The 18/8 stainless steel is usually called 302 or 304 type. There are two variants in common use. One is 316 type, which has 2 – 3%Mo (molybdenum) added for improved corrosion resistance especially in salt environments. The other variant is 17/7PH (type 631), which has 1%Al added for precipitation hardening, and hence a strength level higher than 302 type.

Today, there are two other types of stainless steel, again both named for their microstructure. There is ferritic stainless steel, which has very good corrosion resistance, but not the high strength needed for springs. This is the type of stainless used for car exhausts. Finally, there is duplex stainless steel, which has a duplex microstructure of ferrite and austenite, which is very corrosion resistant especially when molybdenum is an alloying element, and it may be drawn to high strength levels, hence conferring excellent spring properties. IST predict that duplex stainless steel will gradually replace 316 as a spring material because it outperforms the latter with respect to corrosion resistance and strength levels.

All these stainless steels contain at least 12% chromium. It is often said that their corrosion resistance is due to the formation of chromium oxide on their surface, something that happens naturally in air at room temperature. This much is certainly true. However, the very thin oxide on each type of stainless steel differs slightly, and is always made up of several oxide layers, despite being only nanometres thick. Hence, there are differences in the corrosion resistance of the four types of stainless steel. One thing that has always puzzled your author is the fact that addition of molybdenum (Mo) to stainless steels invariably improves their corrosion resistance. So one might ask how the Mo affects the oxide, and Xray photoelectron spectrographic studies have shown that there is almost no Mo present in the oxide – there is concentration of Mo below the oxide, but how does that help? This leads to the second moral of this cautionary tale – the precise explanation for the corrosion resistance of stainless steels is, as yet, incomplete – this fact should keep metallurgists employed for some years to come.

This cautionary tale was written on Armistice Day, soon after the eleventh hour of the eleventh day of the eleventh month (when hostilities ceased in 1918). This day is commemorated every year in the UK by wearing a poppy- *lest we forget* the sacrifice made by so many soldiers in the First World War (and many wars since) in defence of freedom. Many delegates asked the author why he sported a poppy in his buttonhole at the recent Cabwire conference in Milan.

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Readers are encouraged to contact him with comments about this cautionary tale, and with subjects that they would like to be addressed in future tales - e-mail m.hayes@springexpert.co.uk