Using Rapid Alloy Prototyping to Understand the Effects of Residual Elements on a Low Alloy Steel

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1 Abstract

- Scrap steel is a key component of the steel making process, but it introduces unwanted elements known as residuals or tramp elements
- Residuals alter the mechanical properties of the final product
- Increasing scrap content in new steel has economical and environmental benefits
- Future predictions show an increase in residual content in scrap, requiring a better understanding of potential effects
- Many tramp elements are very difficult to remove from the melt so the effects are important to study
- Rapid alloy prototyping (RAP) allows for faster alloy development by accelerating the production of test specimens
- Mechanical properties of RAP specimens are not exactly the same as samples from full scale trials but they do show trends
- Some effects of copper, tin, nickel, chromium and molybdenum as residual elements are presented below

2 Methodology

- The experiments investigate one steel grade with additions of copper, tin, chromium, molybdenum and nickel
- A synthetic scrap is used in samples made from high purity pure powders
- The powder mixes are melted and cast in 20g batches
- The resulting bar casts are homogenised, cold rolled, normalised and cut into test pieces
- Composition of elements and phases are checked using OES, EDX and XRD analysis methods
- The rolled specimen is large enough to produce one small tensile bar with offcuts being mounted to do hardness tests and microscopy

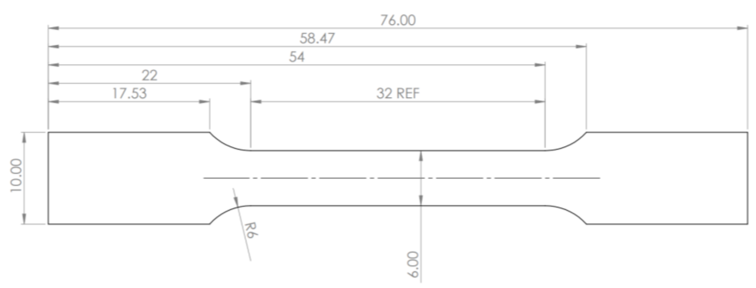


Figure 1 (above): Dimensions of the tensile specimens used

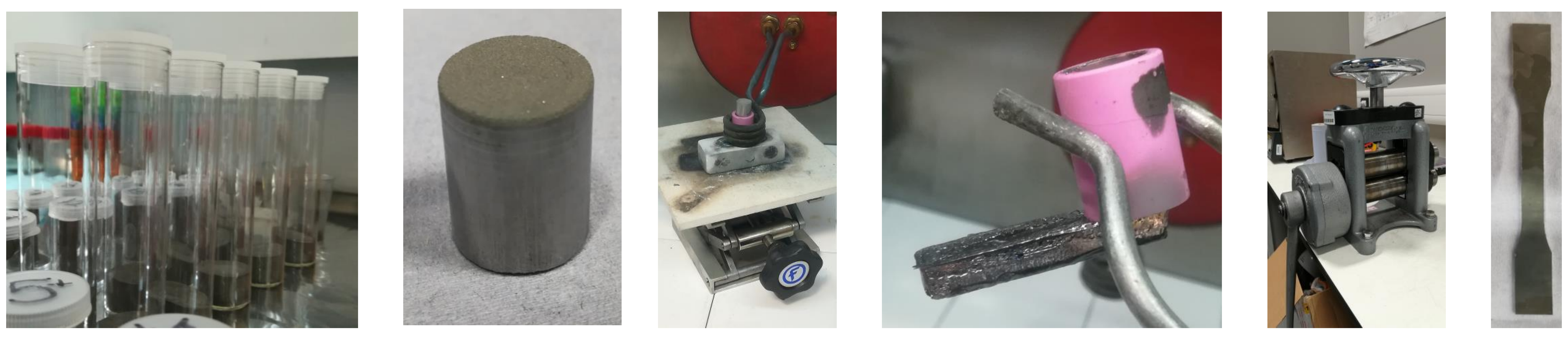


Figure 2: Stages of the sample preparation process; (left to right) powder measurement, compaction, melting, bar cast, cold roll, tensile specimen

3 Microscopy

(a)		Residual wt%	
Cu	1X	0.0310	(a)
	4X	0.1200	
	8X	0.2405	
	12X	0.3605	
	16X	0.4820	(b)
Sn	1X	0.0100	(c)
	4X	0.0415	
	8X	0.0800	
	12X	0.1215	
	16X	0.1600	(d)
Cr	1X	0.0260	(e)
	4X	0.1019	
	8X	0.2015	
	12X	0.3000	
	16X	0.4000	(f)
Mo	1X	0.0025	(g)
	4X	0.0040	
	8X	0.0090	
	12X	0.0110	
	16X	0.0155	(h)
Ni	1X	0.0235	(i)
	4X	0.0960	
	8X	0.1915	
	12X	0.2880	
	16X	0.3830	(j)

(b)	Target wt%	Average wt% (OES)
Fe	Bal.	
C	0.042	0.00534
Mn	0.165	0.153
Si	0.004	0.0103
P	0	0.00612
S	0	0.00662

Figure 3 a&b (above): Residual content of specimens

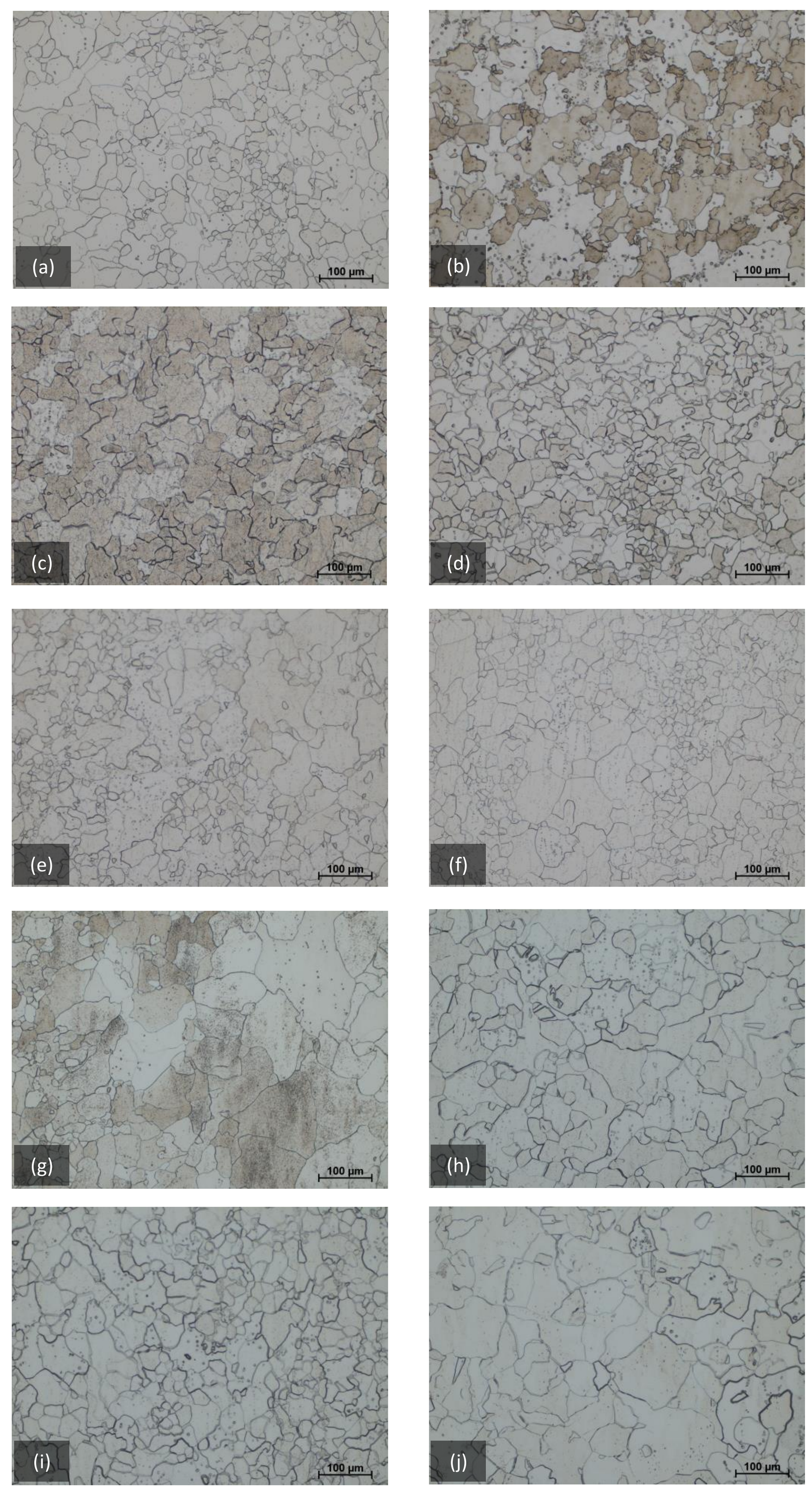


Figure 4 a-j (right): Microstructure of specimens, composition is indicated by the final column of figure 3a

$$C_{eq} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni + Sn}{15}$$

Lloyd's carbon equivalent is used to calculate a carbon equivalent value to compare each composition. The equation does not account for tin so this has been considered alongside copper and nickel

4 Mechanical results

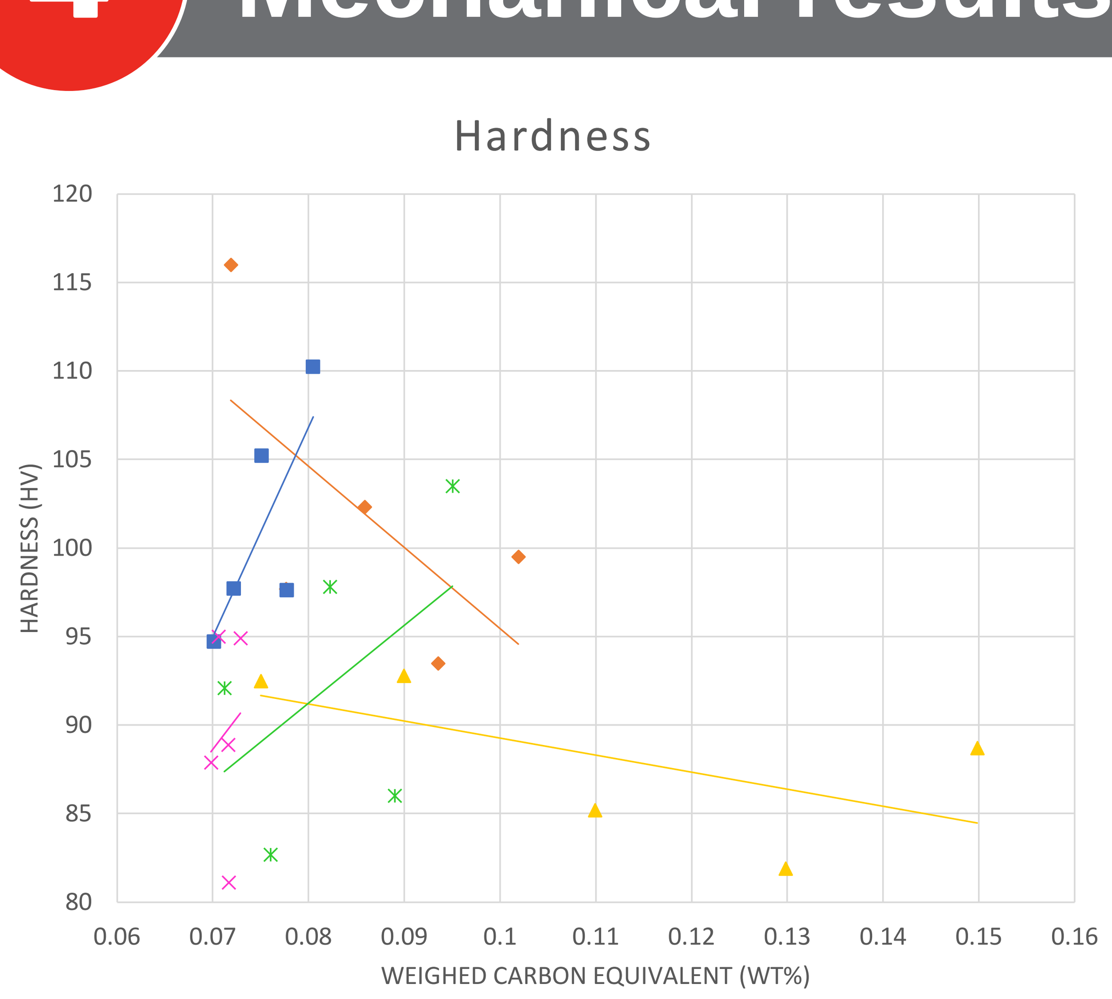


Figure 5: A comparison of hardness values against the equivalent carbon content

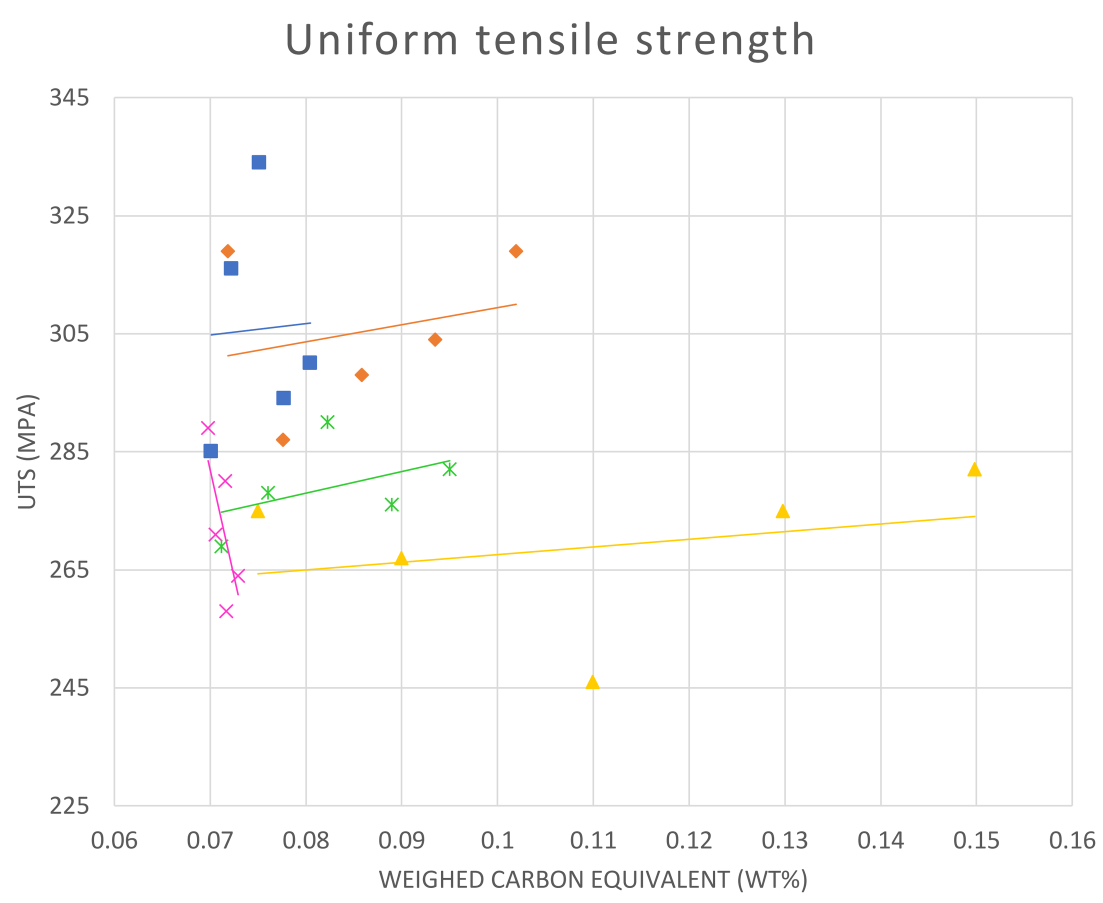


Figure 6: A comparison of UTS values against the equivalent carbon content

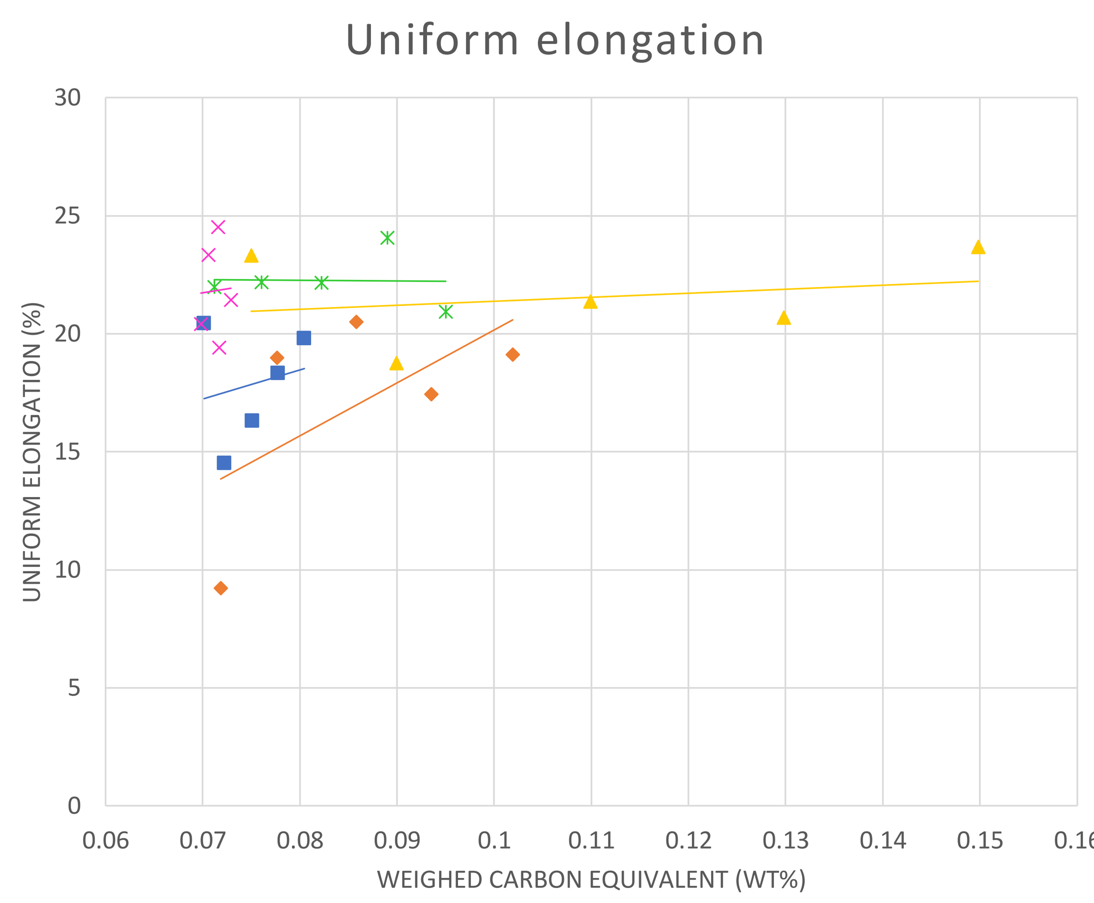


Figure 7: A comparison of uniform elongation values against the equivalent carbon content

5 XRD analysis

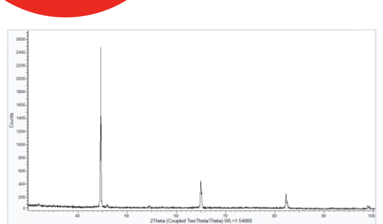
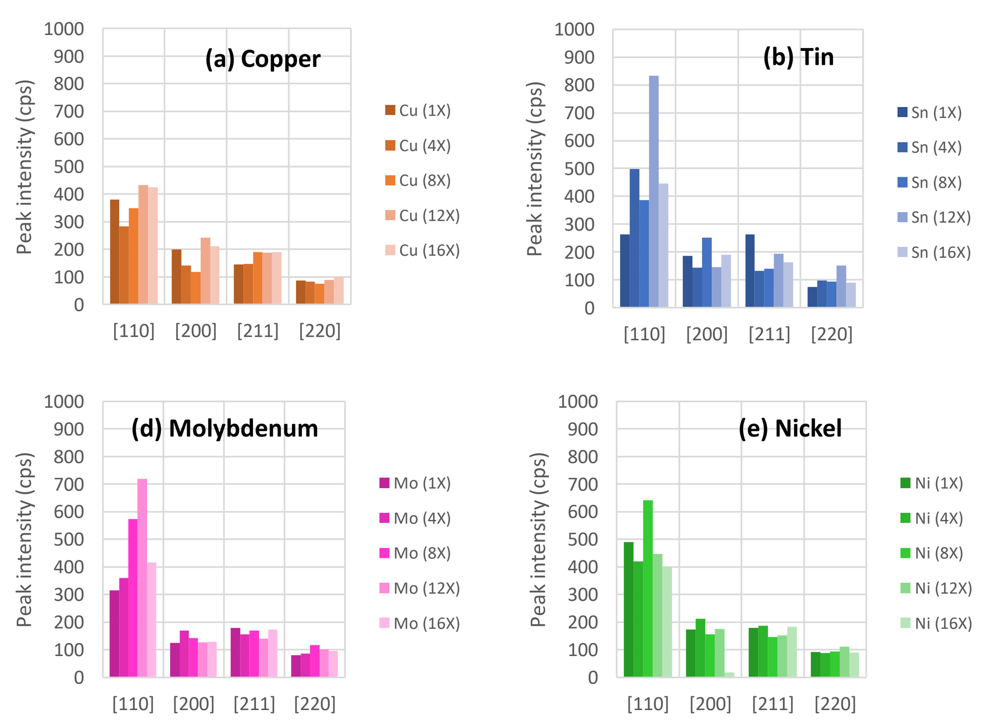


Figure 8: XRD pattern of Cu (1X) with peaks at 45, 65, 82 and 98 degrees, corresponding with [110], [200], [211] and [220] BCC crystal structures

Figure 9 a-e (below): Comparison of the intensity of XRD peaks of each specimen



6 Discussion and Conclusions

- The steel samples have a range of microstructures, potentially due to minor variations in cooling rate after normalisation. The change in microstructures does not strongly correlate with residual additions so is likely a processing inconsistency more than a residual effect.
- The mechanical properties do show expected trends for some elements, although there is a lot of scatter and a few trends contradict what would be expected from literature on the topic.
- The hardness of steel is predicted to increase with all residual elements investigated here but copper showed a strong downward trend and increasing chromium also lead to a slight decrease in hardness.
- Literature predicts an increase in UTS and a decrease in uniform elongation when residual elements are added but those trends are not strongly represented here. It is possible that the levels of residual elements investigated are not high enough to significantly influence the tensile properties. The tests also have produced a large amount of scatter which makes it more difficult to confidently identify any trends that may be present.
- The XRD analysis demonstrated that all the samples had a cubic body-centred cubic crystal structure, as does the industrially produced version of the same grade. This shows some consistency between the RAP method and the industrially produced steel grades.

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