

An Investigation into a Cost Effective Alternative to Copper for Cylinder Expansion (CYLEX) Experiments.

Lawrence Groom
TSG, CT&S, Porton Down, Salisbury, SP4 0JQ

Summary
A series of Cylinder Expansion (CYLEX) experiments were carried out using two types of cylinder material, the commonly used C10100 copper and a generic, cold rolled, seamless, steel alloy. The objective was to ascertain if the much cheaper steel alloy could be used as a replacement for the C10100 copper, a comparatively expensive and rarer material. Twelve shots were carried out, 4 with steel cylinders and 8 copper with measurements taken of Velocity of Detonation (VoD), Volumetric expansion and Chapman Jouguet pressure (P_{cj}). These data sets were then analysed and compared to each other to form a conclusion. A military grade plastic explosive (PE8) was used due to its well defined explosive component of RDX. PE8's handling characteristics also made it a good choice for the stemming of the cylinders.[1]

What is Cylex?
A CYLEX test consists of a metallic cylinder with a thickness of one tenth the diameter and a length 12 times the diameter [2] being stemmed with an explosive which is then detonated from one end. The detonation front forces the cylinder walls outwards which is measured. High-Speed-Video (HSV), Ultra-High-speed-video (UHSV) and Time or arrival devices (TOADs) in the form of Ionisation pins were used to take the measurements.



Cylinder Expansion post-detonation

Velocity of Detonation (VoD)
This is the speed at which the detonation front propagates through the explosive material. A detonation is classified as the speed of reaction reaching and/or exceeding the speed of sound, a slower combustion would be classified a deflagration. It is typically used as a measuring point to classify various explosive materials with values from 8000 meters per second and higher being classified as "high explosives".

Volume Expansion
Defined as how many times over its original volume, the cylinder is able to expand before rupturing. The main factor driving the use of copper is the requirement for the highest value possible from this variable. As a result this was one of the main areas of comparison between the two cylinder materials.

Chapman Jouguet Pressure
The P_{cj} value allows the material under test to be fitted to a Rankine-Hugoniot graph and then assessed for combustion strength. This enables the categorisation of explosive material's detonation or deflagration strength.

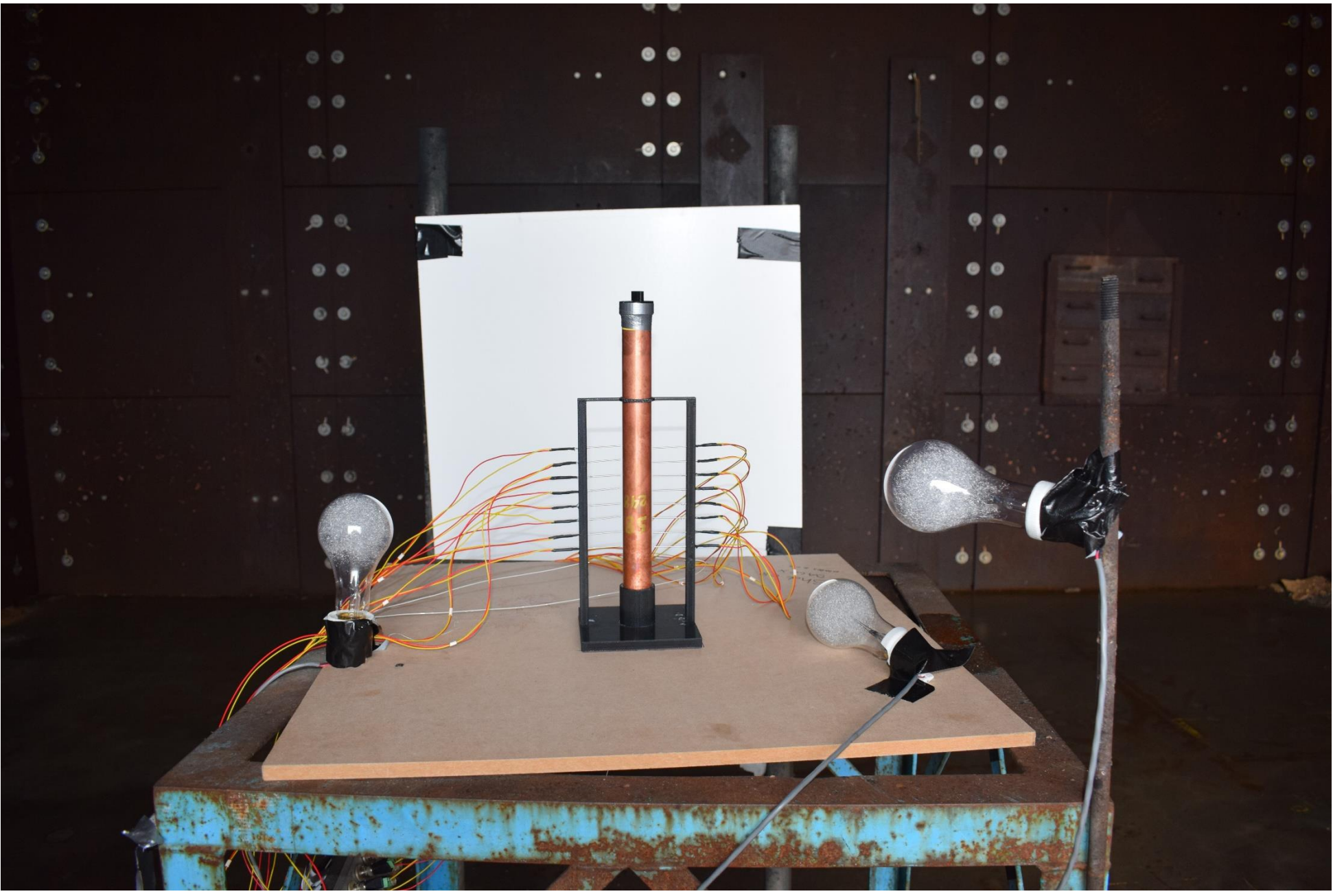
Material properties
C10100 copper is widely used [3] within CYLEX experiments due to its tightly regulated properties and the higher ductility typically present in copper compared to other metals. [4]
A generic seamless hydraulic steel material was selected for comparison to represent the worse case alternative with respect to ductility. This was done to attempt to find furthest possible alternative to C10100 and therefore provide scope for future work within the two extremes.

Testing,
Firings were carried out in a suitably licensed chamber located on the company range with competent personnel deployed to specific roles. The stemmed cylinders were x-rayed to ensure no large voids were present before firing and the HSV systems collected calibration imagery to enable higher accuracy when analysed, TOAD's were affixed to the cylinder stands using an empty cylinder as a guide, exact pin placement and distances were recorded for future analysis.

Results
Velocity of Detonation (VoD) results taken from all three measurement methods showed no coloration between VoD and cylinder material. This suggests VoD of the explosive in use is not affected by tube material. Whilst expansion volumes for copper were superior, steel appears more consistent. This was unexpected given the tight tolerances and purity values attached to C10100 when compared with the steel alloy. Steel's lower P_{cj} values indicate an earlier time of rupture than that of copper as expected. Again, steel's coefficient of variance is smaller than copper.

Conclusions
Whilst copper does appear to be superior to steel with respect to the data sets selected, steel did perform well with more consistent values presented. Lower volume expansions were anticipated with the steel data sets but initial analysis indicates the steel values are suitable.

Future suggestions
Further testing is required to improve the data sets collected to better determine the values of volume expansion for steel. Additional materials should be tested, preferably a material balanced between the comparatively brittle steel and ductile C10100, possibly an Aluminium alloy. Additionally studies could be made into alternative, cheaper, copper materials rather than the C10100. Improvements could be made to the instrumentation to increase precision of the data, such as an additional camera.



Set up of a Cylinder Expansion Test

Velocity of Detonation	Average (m/s)	Standard Deviation (m/s)	Coefficient of Variance (%)
Copper	7965	625	7.8
Steel	7741	821	10.5

Chapman-Jouguet Pressure	Velocity of Detonation Based Method	
	Copper	Steel
	Gpa	Gpa
Average	25.5	21.5
Standard deviation	6.1	0.2
Coefficient of variance	24%	1%

Volume Expansion	Phantom High Speed Video		Sim Ultra High Speed Video		Average of both videos	
	steel	copper	steel	copper	steel	copper
average	3.85	8.61	4.13	8.34	4.04	8.43
Standard deviation	0.7201	2.1221	0.4710	2.7576	0.5376	2.5024
Coefficient of variance	19%	25%	11%	33%	13%	30%

References

1. Chemring Energetics UK, "PE 8 Plastic Explosive" – (Available online)
2. C. Rumchik, R. Nep, G. Butler and B. Breaux, "The Miniaturization and Reproducibility of the Cylinder Expansion Test," in AIP Conference Proceedings, 2012.
3. Richard Catanach, Larry Hill, Herbert Harry, Ernest Aragon, Don Murk, "Cylinder Test Specification" Los Alamos.
4. AZO materials , "Oxygen Free Copper – UNS C10100," (Available Online) <https://www.azom.com/article.aspx?ArticleID=6314>.