MINERvA Test Beam Detector Steel Measurements

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Abstract

The measurements of the steel absorber for the MTest test beam calibration of the MINERvA detector are analyzed for uniformity and absolute material thickness. In this note we also discusses the effects on test beam and full MINERvA data analysis. We find that, pending some checks on the scale calibration, the steel is quite uniform. It is adequate to model the steel in the test beam detector as identical pieces of thickness 2.602 cm and the standard steel density 7.847 g/cm^3. In this note I comment further on the practicalities of the simulation which still contain placeholders for uncertain materials.

1 Introduction

Jim Kilmer and the crew at Fermilab obtained thirty-two pieces of inch-thick steel from the boneyard after they cut the steel to 43 inches (109 cm) square for use in the MTest calibration runs. Then they measured the dimensions and weight of these same pieces. This document contains the details and analysis of those measurements.

This paper as well as Jim's measurement spreadsheet are together as docdb/2630. This documents supercedes the presentation in MINERvA docdb/2213 (31 January 2008)[1].

Jim Kilmer also has a presentation in docdb/1558 with some chemistry discussion for this steel[2].

2 Measurement details

The technique and accuracy of these measurements were obtained as follows:

- X and Y dimensions of the square, via tape measure to 1/16 inch.
- Thickness measured with (what) to precision of 0.001 inch. Don't yet have information on the tolerance of this machine, but see analysis below.
- Weight was measured with a scale whose absolute calibration had not been determined. The precision of the weight measurements is reported to one pound (0.2% of 540 pounds), reckoned from a scale with 10 pound divisions.

An important piece of information to confirm is the absolute calibration of the scale, which is an older 1000 pound mechanical crane scale which reads out the weight of the object hanging from it with the smallest division being 10 pounds. The operator made an estimate within this smallest division which probably has a precision of plus or minus two pounds. The 540 pound steel plates are too heavy to use on their good new digital scale, but someone should still do a calibration check of this older scale.

2.1 Chemistry

This is the measurement of the chemistry supplied by Jim Kilmer in docdb/1558[2]. I am not sure what it means that all the boneyard measurements are reported as “max”. Possibly those measurements were not intended to be a proper material assay, but rather were made for comparison with a steel specification from which we conclude this steel is closest to the low carbon SAE1010 standard.

Weight %	Boneyard	SAE 1010	SAE 1020	A-36
Carbon	0.06 max	0.08-0.13	0.18-0.23	0.26 max
Manganese	0.40 max	0.3-0.6	0.3-0.6	0.75 max
Sulfur	0.01 max	0.05 max	0.05 max	0.05 max
Phosphorous	0.01 max	0.04 max	0.04 max	0.04 max
Nitrogen	0.008 max			
Silicon	0.40 max			
Aluminum	0.05 max			
Chromium	0.05 max			
Copper	0.06 max			0.2 max
Nickel	0.06 max			
Molybdeneum	0.01 max			
Vanadium	0.01 max			
Niobium	0.01 max			
Density		7.832	7.86	

2.2 Industry standards

Until a check of the calibration of the 1000 pound scale is completed, our assurance of the absolute accounting of the steel and its uniformity is partly based on comparison to industry standards.

The industry standard thickness tolerance for rolling steel is 0.070 inches. All our measurements are well within this specification, and this tolerance doesn’t yield further useful information.

The industry standard density for this type of steel is 0.2835 lbs/in^2 (7.847 g/cm^3). The measurements of this particular set of steel plates agrees with this exactly, suggesting that the scale might be well calibrated. For now, the agreement in the spec and our measurements is our assurance that things are correct.

There are, however, different types of steel with different compositions and therefore densities, for different applications. A variety of places on the internet[3] suggest that the density might range from 7.75 to 8.05.

3 Analysis of uniformity

Consistency of five thickness measurements

The most relevant piece of information for our physics analysis is the total material seen by a particle passing through and possibly interacting with the steel. Specifically, the convolution of thickness x density, expressed in grams/cm^2 is the most important thing to get right in the simulation. Getting the thickness and density correct separately is also desireable, but the potential bias will be quoted from the convolution. The measurements we have taken allow us two ways of understanding this calibration. We have a complete set of xyz and weights from which we can determine the g/cm^2 value. We can also understand these measurements in the context of the industry standard density for this steel and our thickness measurements.

A guiding idea is that if our steel is adequately uniform, we will use a single thickness and density for simulation and analysis, and quote an error or bias based on the accuracy of these measurements. If the steel fails to be uniform enough, then we may have to specify the thickness and density individually for pieces of steel, with the cost of significant effort at the analysis stage.

The five thickness measurements for each plane were taken from the four corners and the center. The standard deviation computed from these five measurements was 0.006 inches with only two planes showing five measurements with standard deviations of more than 0.01 inches. I conclude that for our purposes the steel plates are uniform over their entire area to better than 1%, and the error on "uniform thickness" and a thickness measuremtn based on the average of five measurements for a single plane can be quoted as approximately 0.006 / sqrt(5) = ± 0.003.

The collection of planes themselves differ in thickness. The thickness average of 32 planes is 1.0245 inches with a standard deviation of 0.0120. The thinnest planes are 1.006 inches while the thickest are 1.048 inches. In principle, we could specify the thickness of each plane individually for simulation and analysis, but we want to explore whether it is reasonable to consider every plane to be the same. That standard deviation suggests that the fluctuations around an average plane are at the 1.2% level, which is good.

If the planes are randomly inserted into the detector, then we could naturally take the average thickness of 1.0245 inches. For tracks (dE/dx) and showers that pass through a large statistical collection of planes, one might suppose that a potential bias from using this thickness in the modeling and analysis is around 0.0120 / sqrt(32) = 0.002 inches (or 0.2%). We might prudently identify a labeling scheme for these planes and record which ones go in the front of the detector, because a 1% bias is possible if the first few planes represent a particular fluctuation from this mean.

There is not much interesting information in the variation on the xy dimension, it is neither important for our physics nor was it part of a careful specification. All the measurements are within 1%. However, these measurements allow us to estimate the density of steel for each of these planes, which is very relevant information.

When the density is calculated via weight/volume using the xy and thickness measurements, the average density comes out to be 0.2836 lbs/in^3 with a standard deviation of 0.0023. If this was considered a straightforward measurement of steel density, we would quote 0.2836 ± 0.0004, which is a precision of 0.14%. The actual error on this measurement comes from the calibrations of the xy measurement (accurate to 0.15%), the thickness (precise to 0.1%, but not sure of the tolerance/accuracy/calibration of this instrument), and the calibration of the scale used for the weight (unknown).

This density compares quite well with the standard density of 0.2835 lbs/in^3, and is well within even the most optimistic esimates of what the uncertain calibrations of the scale and thickness gauge might be.

Three odd pieces

In the sense that the density measurement represents a measurement of the consistency, I can report that there are three pieces of steel that seem to be a bit odd. In the spreadsheet they are numbered 10, 17, and 25, and have a density that is lower than the average by about 2%. Based only on the information in the spread sheet, the first two have weights that are tied with four other pieces for being the lowest, while the latter has the second highest value for the thickness (and therefore volume). Though these values are at some extreme, they are not uniquely extreme. The spreadsheet has been checked for typos and there is no indication that an error was made.

If these three pieces are truly unique at the 2% level, we may consider placing them at the back of the detector. We can then recalculate the average thickness and density of the remaining 29 pieces to determine our standard steel plate. In this case the average thickness for a standard piece of steel would be essentially unchanged: 1.0234 instead of 1.0245, a difference of 0.1%, which is negligible and not worth bothering about. The apparent density of the 29 piece sample climbs from 0.2836 to 0.2842, but is also still within 0.1% of standard steel.

4 Conclusion

Until the scale calibration can be cross checked or verified, we can take the density of standard steel 0.2835 lbs/in^3 and an average thickness of 1.0245 inches. This represents steel that is about 2.4% thicker than our nominal spec (one inch of standard steel) but is satisfactory for our application because we know the actual thickness.

For use in the Geant4 simulation, these need to be converted to metric.

0.2835 lbs/in^3 is 7.847 grams/cm^3 with an error of 0.1% because our measurements seem to agree with the standard quite well. This might not be an adequate estimate of the bias.

1.0245 inches is 2.602 cm with an error of 0.2% for measurements that statistically sample many planes.

This means the effective steel thickness is 20.418 g/cm^2 with an error of 0.2%.

On the other hand, a placeholder for steel is in the simulation already as "pure iron" with a density of 7.87 g/cm^3. For the time being the simulation will keep this placeholder density same as full MINERvA and I will use a slightly lower thickness of 2.594 to get the same g/cm^2. When that placeholder is updated, the MTest number should also be changed, or a separate entry for MTest steel should be created.

That placeholder is listed as pure iron, while the boneyard steel we are using has 0.4% Manganese and 0.4% Silicon and another 0.4% other elements. We have not made any attempt to account for these 1% effects on the composition, and they may in fact be negligible.

These values have been put into the MTest detector simulation as of July 2008.

Bibliography

[1] R. Gran, "Rik's summary of Jim's steel measurements" presentation docdb/2213, 31 January 2008.

[2] J. Kilmer, "Boneyard Steel" presentation docdb/1558, 27 April 2007

[3] Steel Density: S. Hawkins http://www.madsci.org/posts/archives/1997-12/874069066.Ch.r.html and K. Sutherland http://hypertextbook.com/facts/2004/KarenSutherland.shtml