Determining the Immeasurable Pipe Grade

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Introduction

As part of the regulations published in October of 2019, PHMSA requires operators that do not have traceable, verifiable, and complete (TVC) records to conduct material verification in accordance with §192.607 to document physical pipeline characteristics and attributes, including diameter, wall thickness, seam type, and grade. According to PHMSA's annual report data for 2020, there are approximately 3,000 miles of gas transmission pipe with non-TVC specified minimum yield strength (SMYS) records. Although yield strength (YS) can be measured through various non-destructive methods with a reasonable degree of accuracy, YS by itself does not address the question of pipe grade (and hence, SMYS) since a single YS can span up to six different grades based on the allowable ranges of YS in API 5L.

When the categorization of something is imprecise, there is a desire to make something that is measurable (such as YS) a direct indicator of something that is not measurable (such as grade). That is to turn it into a problem based on the strong syllogism of, if *A* is true then *B* must be true. But in most problems of any consequence, the lines of division are not that clearly drawn, and we are left with the weaker syllogism that if *A* is true, *B* becomes more plausible. Though the YS and grade are related, since higher grades have higher minimum YS, they are not the same. Grades are an assigned label that relates to chemical composition, processing, testing requirements and a range of YS. The allowable range of YS for any grade has a wide tolerance band in API 5L that overlaps with up to six grades. Additionally, the YS will vary around the circumference, along the length within a joint and from joint to joint within a single lot of pipe. Slight differences in the processing of the steel can lead to significant changes in YS.

The mapping of a YS with no additional information into a single independent classification is a fallacy, that asserts one's private wishes as the reality of nature. To accept this as true requires the ignoring of manufacturing standards and well-known practices. Figure 1 shows the distributions of YS based on the aggregated statistics from API 1176 for the different grades based on the assumption of being normally distributed. If the YS from a joint of pipe with an unknown grade is 61 ksi (even ignoring any measurement error) it would be a weak conclusion to assume that the grade is X60. By reviewing Figure 1 it can be seen that 61 ksi could be well within the range of X42 and could even be as low as Grade B, which would be unconservative by as much as five grade levels.

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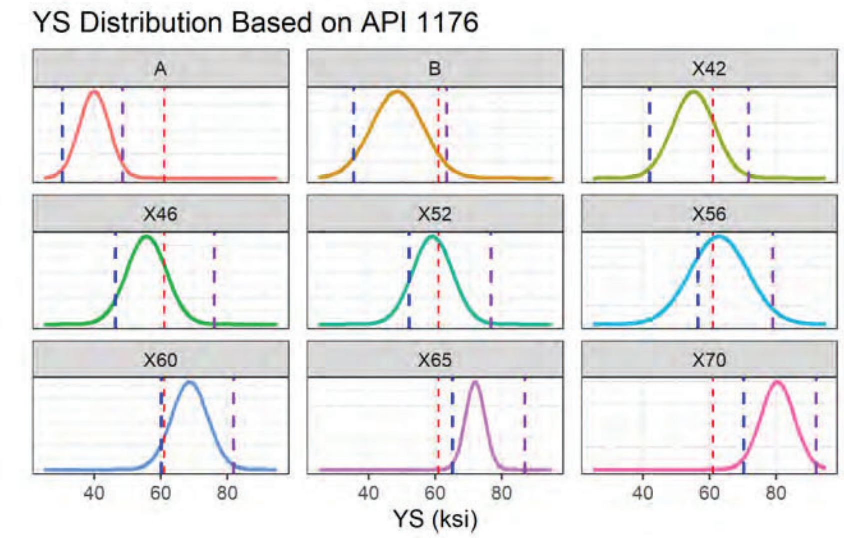

Figure 1. API 1176 Ranges

Figure 2 shows the empirical distribution of destructive YS from a database of about 10,000 samples of known grade overlaid with the limits of YS from API 5L. As with the distributions from API 1176 this again shows that a YS of 61 ksi is not exclusive to X60. It's the least likely of any of them based on destructive test data and Grade B is even more likely than X60 for that YS. But this also demonstrates that YS viewed in isolation is a vague indicator of grade. of grade at best and will probably lead to a gross over-estimate of grade.

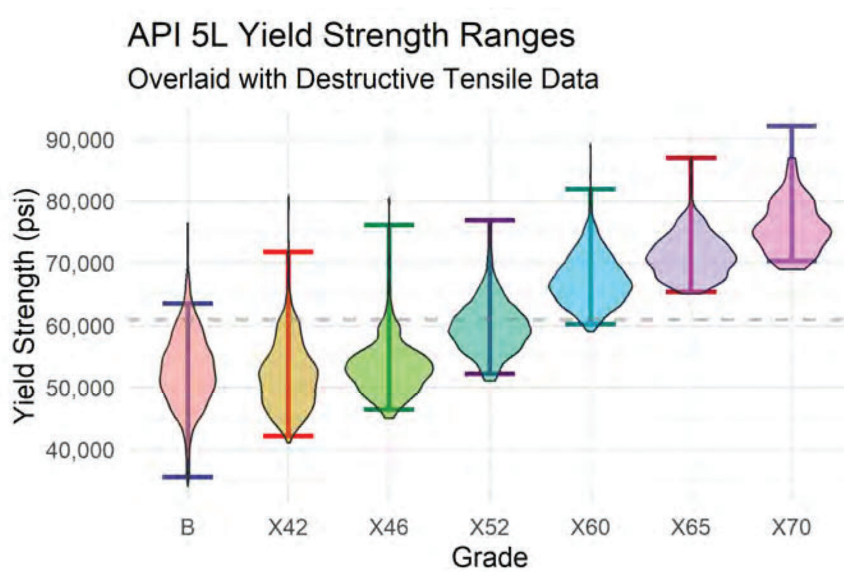

Figure 2. Probability of Exceeding 60 ksi

Why do I care?

One vane of counter arguments to grade determination is that if the YS is high enough to meet the requirements of the higher grade why should anyone care if the manufacturer placed some other

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label on it. Figure 3 is a histogram of YS to SMYS ratio from the same data set used in Figure 2. The ratio has a long right skew with the average YS exceeding SMYS by 13%. So, it is a near certainty that a random joint will be above the minimum. But keep in mind that you are taking a sample of one and making a conclusion presuming that single sample of field YS will all be the same for all the joints under consideration. The YS is only one part of the requirements for the assignment of grade by the manufacturer. A grade also implies chemistry, post weld heat treatment, elongation, and mill pressure test, none of which a NDE strength test provides any information about.

The requirements of §192.607(g) also state that except for one specific condition, "*The material properties determined from the destructive or nondestructive tests required by this section cannot be used to raise the grade …*". It is apparent from this that PHMSA's intent for the material verification requirements is to verify grade not YS. Basing the grade assignment solely on YS carries a significant risk of overestimating the grade by two or more grade levels because of the bias and the skew in the YS/SMYS ratios.

API 5L quality sampling requirements heavily favor the manufacturer and are very unlikely to reject a lot that was partially defective. Suffice it to say there is ample opportunity for pipe that is above or below the YS specifications to make it past the inspection requirements of API 5L. The standard doesn't even require that the sample be from the finished pipe, it can come from the plate or coil and there can be a ± 10 ksi difference between plate and finished pipe. Given the wide range of allowable YS and lax sampling requirements there is no guarantee that the joint that is being verified came from the higher end and the uninspected adjacent joint is from the other end of the range, thereby overestimating the limiting YS of the system. This is coupled with the variation that can be seen within a single joint of pipe. Studies have shown that variation circumferentially and longitudinally within a single joint can exceed 6 ksi alone.[1] So by using YS alone as a predictor, depending on which joint or where you sample on the joint it will change your answer of what the grade is. Which is obviously a logical inconsistency given there is only one grade that was designated by the original designer. This shows that YS alone will lead to varying assignment of grade, probably over estimating grade, which can't coexist with the representation of the manufacturer's representation of it being that it meets a single and very likely much lower grade.

[1] PRCI: Final Report on Tensile Property Variation in DSAW and ERW Line Pipe, PR- 187-9602, July 1999

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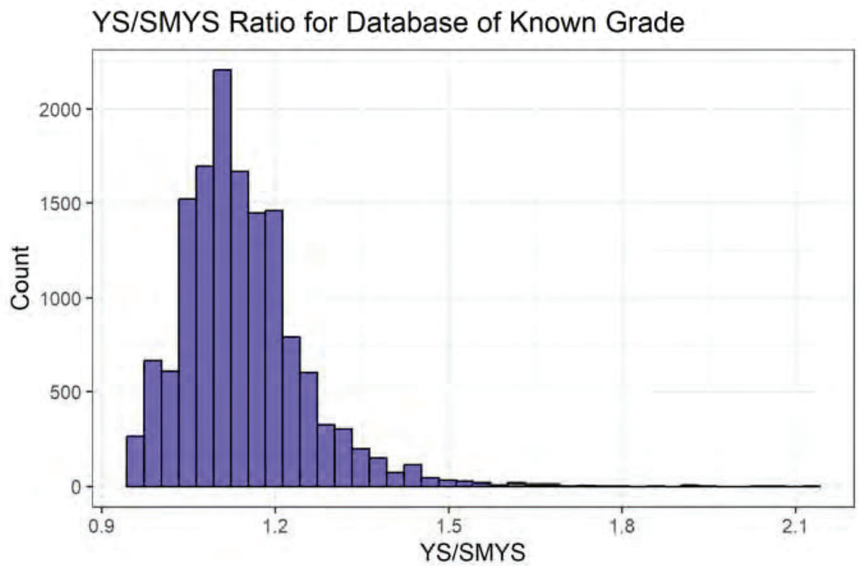

Figure 3. YS/SMYS ratio

Figure 3 is based on multiple grades, over multiple decades from several different mills. But in the following plot it shows the variation that can occur within a single mill between sequential runs of X70 pipe. It is important to note that the amount of variation is not just between runs but even within a single run. Similar to the data seen in Figure 3 the average YS exceeds SMYS by 13% with the ratio extending out to over 25% above SMYS to almost 90 ksi and only one sample out of 300 had a YS of 70 ksi. If the grade wasn't known ahead of time it would be very difficult to determine grade based only on YS with the range extending almost 20 ksi.

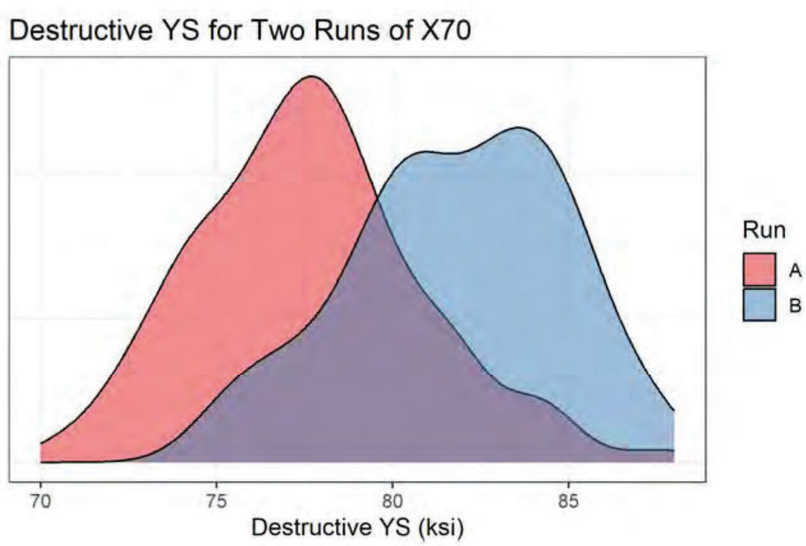

Figure 4. YS for Runs of X70 pipe

Determining Grade

Ideally there would be some key indicator that would unequivocally separate one grade from another. But that is simply not the case. API 5L requirements for composition only state the maximum allowed for most elements and even those maximums have changed over time with various editions. For instance, there was no limit on the amount of carbon until the 3rd edition of API 5L and the limits on the maximum manganese content has changed significantly over the years as shown in Figure 5.2 It is also important to know that prior to 1948 there were no “X” grades, only grades A, B & C in 5L even then only X42 existed as a standard until X46 and X52 were introduced four years later. But even with them not existing as a official grade, they still existed in practice because of the caveat that allowed for the making of any YS pipe by mutual agreement between the customer and manufacturer, leading to material test records that state the grade as something like, Grade B - 52 ksi.

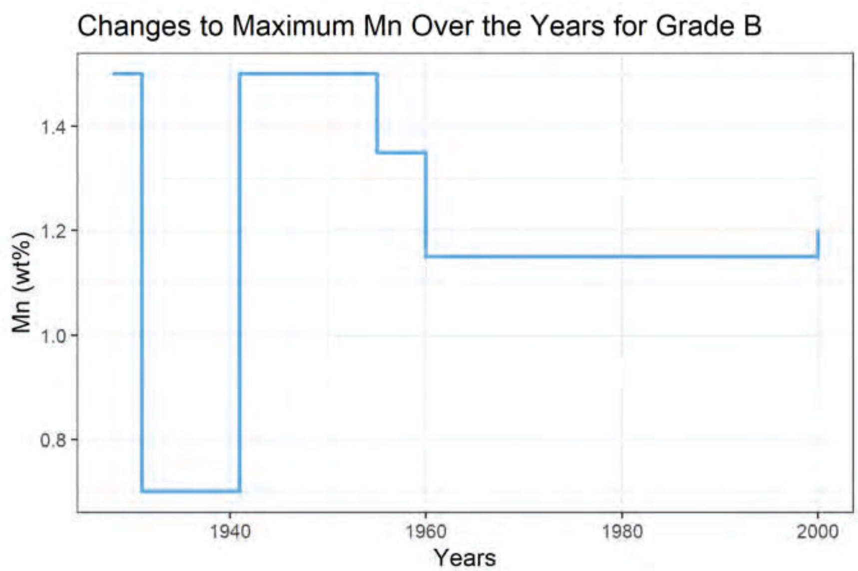

Figure 5. Maximum Mn Content Allowed

Empirical Distributions vs. Decade

Figure 6 shows that composition trends are not the same by grade. Some are relatively constant in their trend, increasing or decreasing with higher grades but some elements like carbon increase from the lower to the middle grades and then start decreasing through the higher grades. Like YS any given value for composition is going to cross multiple grades and there is no clear separation between them.

[2] ASME CRTD-Vol. 43, History of Line Pipe Manufacturing in North America

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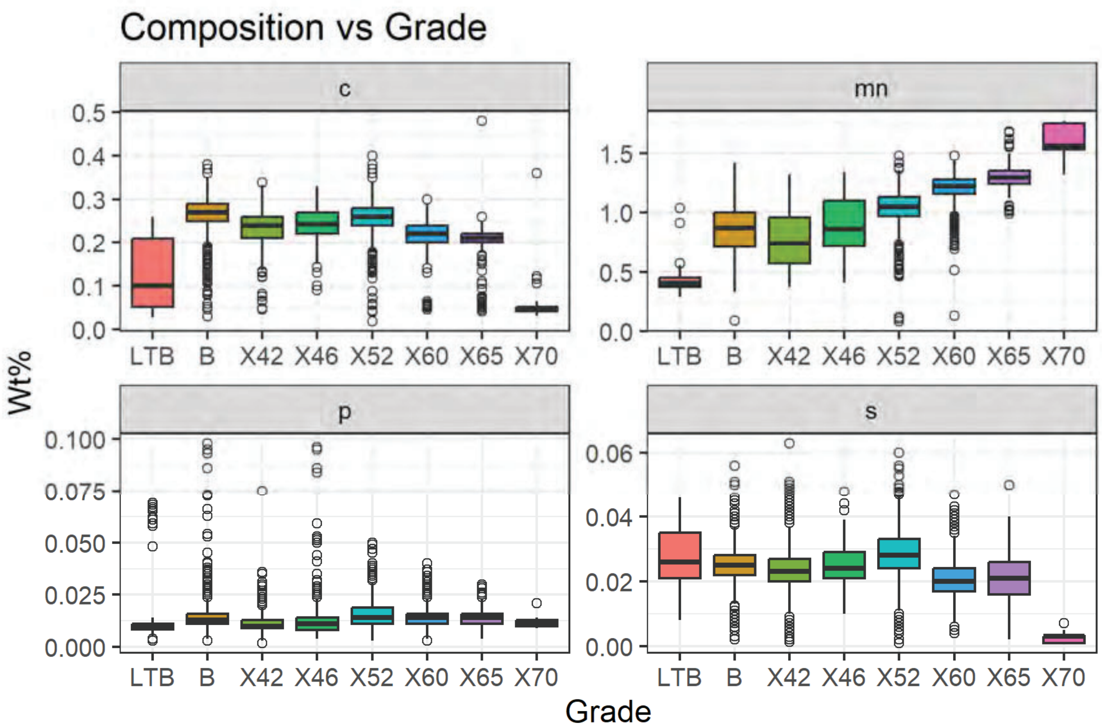

Figure 6. Empirical Distributions of Composition

It is self-evident that neither YS nor composition viewed in isolation will be able to directly lead to a defensible determination of grade. This may seem to make the requirements of §§192.607 and 192.624 a hopeless task considering the inconclusiveness of things that can be measured non-destructively. But this is not the case. Viewed in isolation they are vague indicators of grade, but the information taken together can start to paint a picture. Unfortunately, due to the large overlaps in all these variables there is not going to be some closed–form solution to the problem where each value is multiplied by some constant to arrive at a probable grade. However, with the accessibility of machine learning (ML) models and the relatively cheap processing power available nowadays it is possible to arrive at a probable grade. Note the use of the term, "probable". A ML model can identify trends that are not evident by simple inspection of the data and arrive at a probability for each classification but even then, the grade with the highest probability might not be the correct answer since any ML model is going to have a percentage of misclassifications. It becomes necessary even with the ML model for the decision maker to avail themselves of all the information that is available. Things like microstructure, diameter, wall thickness, vintage all provide inferences about the likely grade. Any decision to be defensible needs to be plausible and consistent; plausible given what was known about the pipeline beforehand and consistent with the observations. If the prior knowledge and observations are incompatible with each other than one or the other is wrong and should be reevaluated. Either the information you thought you knew beforehand was mistaken and an alternative hypothesis needs to displace it, or the observations were in error.

But using a classification ML model combined with all the information both known beforehand and observed, operators can now make decisions with a high degree of certainty. Rather than saying is this grade correct they can now weigh all the evidence and be able to decide if the decision will stand up to scrutiny and minimize the risk of misclassification that comes with using YS as a sole determiner of grade.

Conclusion

There is never going to be an easy answer to the undocumented grade question since it can't be directly measured and the things that can be measured have high degrees of uncertainty relative to the grade. However, by incorporating all the evidence available, an informed decision can be made. There is no absolute certainty in statistics since the question involves an unknown population, you are not given the parameters as part of the problem statement. You must use the observations combined with previous knowledge to make a decision. You can never remove all uncertainty but with the weighing of all the evidence, a defensible judgement can be made that is beyond a reasonable doubt. The case for grade is an accumulation of evidence not a measurement made in isolation.

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