Troubleshooting Common Quality Issues in Wire Raw Material

by Laurence Claus

There are many ways that fastener manufacturers can make quality deficient parts. If one attempted to classify the source of all these different failure modes and quality issues, they likely would emerge with three or four general categories. One of these general categories and perhaps the single greatest contributor to end product quality issues is the quality of the raw material from which every fastener starts.

This article will explore some of the most common quality issues related to raw material and seek to simply describe how each specific issue has an impact on final part quality.

To successfully explore the most common quality issues in raw materials one must first have a very basic understanding of the raw material utilized by fastener manufacturers and how it is produced.

Of course, the actual purchase and specification of raw material is very much a personal company choice that is determined by years of experience in honing individual manufacturing processes as well as supplying appropriate feed stock to a wide variety of machines and equipment. Obviously, this means that some fasteners may be made from very different raw material feed stock types such as coiled wire, coiled rod, cut-to-length bars, or individual blanks. For the purpose of this article, however, we will narrow the manufacturing process down to just cold heading, thereby, focusing exclusively on raw material wire and rod that is in coiled form.

If a curious friend were to ask you how your company makes fasteners, you might simply reply by "cold heading". Although that term is understood by you and your industry colleagues, it would make little sense to your non-initiated friend. Therefore, you might get a follow-up question to describe what that means. How would you do this in a simple fashion that your friend is sure to understand? Perhaps you might describe the process something like this, " We take raw material (usually steel), feed it into one of our machines, smash it with a tremendous amount of force in an effort to redistribute the metal into a desired shape, and collect the newly formed part to finish the process with other subsequent operations." Although you may choose slightly different words, I am relatively positive that the process described would be similar to the example I have shared here. And if we analyze this simple description for what it communicates, what does it say about the raw material? Essentially it says that we must have raw material that we can depend on to consistently redistribute itself into complex shapes when exposed to tremendous forces without bursting, cracking, or fracturing. In other words, we require raw material that must consistently perform under extreme conditions. Not all raw material can supply this desired performance, and, thus, fastener manufacturers must rely on a premium quality material, which we normally refer to as Cold Heading Quality or CHQ wire and rod.

Where does this material come from? The simple answer is from a steel mill that is capable of producing such level of performance quality material. In North America, there are only about eight to ten steel mills that are capable of this task.

Regardless of what part of the world or what supplier the CHQ material comes from, the production process is pretty similar; material is melted, cast, hot drawn, and finished. The process begins by melting or creating a batch of material from some form of feedstock. For steel, CHQ quality materials are usually melted in an Electric Arc Furnace (EAF), although other steel making processes can be employed. The steel making portion of the cycle is an iterative process of several steps. The furnace is charged with "iron units", which generally are a mix of scrap steel and some form of more refined iron. This "charge" is melted down and basic refinement begins. The resulting product of this stage of the process is an intermediate of the final desired product. In concept, imagine we were making fudge swirl ice cream. We first start with making vanilla ice cream and then add all the special ingredients to get the fudge swirl variety we want. By analogy, the product of the EAF is like the vanilla ice cream, it is definitely a steel product but not yet the exact variety we want. Therefore, after the steel is melted and refinement begins in the EAF, it is transferred into a large crucible called the Ladle. In this stage all the finishing touches are added and the steel becomes the finished variety we seek. Most often this stage includes a vacuum degassing process where the Ladle is placed into a chamber and a vacuum pulled. This removes unwanted gases and other impurities. It is important to be aware that not all steel makers utilize this vacuum degassing step. Surely, however, those mills that incorporate this process are producing a higher quality steel so that knowledge of your suppliers process is important in knowing what you have to work with.

Following the ladle refinement, the finished steel is transferred into the caster where continuous strands of steel emerge, are cut, and become what is known as a billet. Billets vary from steel mill to steel mill in shape and size, however, one billet is the input into the hot rolling mill and results in the output of one long continuous coil.

The hot rolling process involves heating the material up above its critical temperature. It then proceeds to go through break down stands which progressively reshape and reduce the size of the billet to the finished hot rolled rod size. The end result is a continuous coil of what is known as "Green Rod".

At this stage, one might look at the coiled material and conclude that it was ready to be used to make fasteners. In fact, it would be hard to fault someone in arriving at this conclusion because a coil of Green Rod looks remarkably similar to a coil of finished wire. However, drawing this conclusion would be incorrect. The "Green Rod" has some significant deficiencies. At this stage, the surface may have a great deal of scale or other surface detritus adhering to it, which would be extremely detrimental to tooling. The microstructure is inconsistent throughout the length of the coil, so that performance may vary greatly from one end to the other. Finally, at this stage, although the material looks round and consistent in size, in reality, it possesses significant variability in both dimension and roundness.

Since most manufacturers cannot successfully manufacture parts under these conditions, a final finishing process step must be employed. There are many options here, so we will simply categorize this as the finishing step where "Green Rod" is transformed into finished wire. This often employs cleaning the surface, coating the surface, annealing to achieve a consistent microstructure, and drawing to improve the dimensional and roundness characteristics.

The outcome of the above process is finished CHQ wire.

Unfortunately, there are places in this process where hiccups occur, resulting in quality issues. Now that we have a general understanding of the process to manufacture coiled CHQ wire, let us explore the places where things can go wrong.

Seams:

In my experience anytime a manufacturer has part problems which they believe are due to the raw material, it is blamed on a seam. This is unfortunate because although seams are likely the most common of raw material problems, they are not the only problem and, in fact, there are other discrepancies that appear similar in nature or result in similar problems on finished parts. What, therefore, is a seam? A seam is an artifact of the casting and rolling process. When the billet ends up with a small surface defect, maybe a small void or depression, that is not removed prior to rolling, it will not close up in the rolling process but rather stretch out. The depth and length will depend mostly on the size of the imperfection from which the seam originated and the final diameter of the rod. If this is not quite clear, imagine taking the tip of a pen or other blunt nose tool and pressing a small hole in the surface of a block of taffy. If you then grabbed this block with both hands and began to pull on it, what happens to the circular hole that you poked in it? You would see that the hole would simply begin to elongate as you stretched the taffy. If you stretched it long enough and far enough that circular hole would no longer be recognizable as a hole or even a circular depression, but rather a long continuous line. If you cut through the taffy across that line you would find that the taffy was not fused together for some distance into the stretched block and would appear like a crack. This is exactly what happens when an imperfection in the surface of a billet is broken down into much smaller diameter rod.

Seams are particularly insidious because they can occur anywhere in the coil and often for only short lengths. This means that they are difficult, if not impossible, to discern or to remove from the coil prior to using it. Rolling mill operators have done much to improve their processes over the years, but this is one of those problems that even the best supplier cannot completely guarantee a coil is free of.

Figure 1 shows a seam on the surface of a section of wire. A seam will always be running lengthwise with the axis or spiraling around (in the case of some non-ferrous materials where process steps involve twisting the rod during processing). Figure 2 shows a wire sample in cross section. One of the ways that one knows it is a seam is that the crevice (seam) will always point towards the center.

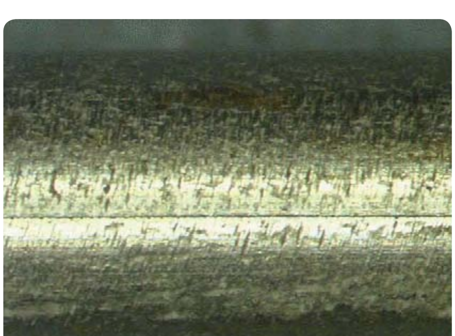

Figure 1: Wire Seam

Figure 2: Wire Seam in Cross Section

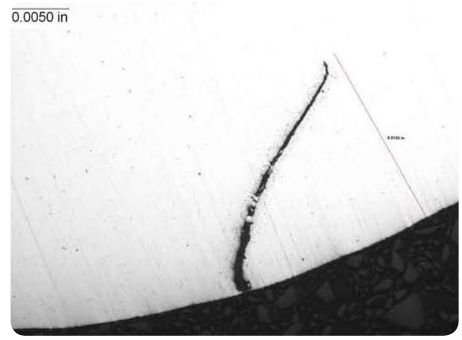

Figure 3: Wire Lap in Cross Section

Laps:

Laps in wire and rod usually appear on the exterior similar to a seam. Occasionally, a lap will appear differently than a seam in that it will be very irregular along the surface or show up as two parallel lines. The definitive way of determining a lap from a seam, however, is to view it in cross section (See Figure 3). Whereas a seam will always be pointing towards the center, a lap can point in any direction.

Laps are created during the hot rolling process. When the rollers that reduce the diameter are just slightly out of alignment, they can roll over a small flap of material. As this is rolled through subsequent rolling stands this flap is folded over and pressed into the surface. Unlike a seam, because laps are generally the result of a tool misalignment, the discrepancy is found over long sections or even the entire coil.

Figure 4: Scratch in Cross Section

Scratches:

Scratches are the result of mechanical damage during the rolling or drawing process. If any kind of debris or surface imperfection is found on the rolling or drawing tools, it can have the result of scratching the surface. Again, a scratch may appear like a seam or lap. However, when viewed in cross section there will be no open crevice like one finds with a seam or lap. Figure 4 illustrates a scratch in cross section. It is obvious that the material is compressed but not an "open wound" in the area of the scratch.

Figure 5: Cracked Head from Wire Seam

Consequences of Seams, Laps, and Scratches:

In many cases seams, laps, and scratches have no obvious detrimental impact on finished parts. However, all three discrepancies are vulnerable to the excessive forces exerted during forming and can result in a finished part crack or burst. Most often, these discrepancies sufficiently weaken a part that is undergoing significant forming and result in cracked heads or flanges. Figure 5 shows a cracked head that is the result of a seam.

Inclusions:

When someone refers to steel (or other metal) as being "dirty", they are making a statement about inclusions. Inclusions are chemical compounds and non-metals that are entrapped or present in the steel (or other metal). Although there are instances where certain non-metallic compounds may be advantageous, as a general rule the presence of inclusions is detrimental. Even very small amounts of certain inclusions can have a dramatic impact on the performance of the steel (or other metal).

Inclusions are generally classified into two groups; exogenous inclusions and indigenous inclusions. Indigenous inclusions are generally small in size and form from chemical reactions with residual or tramp elements within the metal. Exogenous inclusions come from outside sources and are entrapped during the melting or casting process. They tend to be remnants of the slag layer or mold refractories. Exogenous inclusions can vary dramatically in size and large exogenous inclusions near the surface present a real danger as stress risers or failure initiation sites.

Insufficient Coating:

One of the absolute necessities of the cold forming process is adequate and effective lubrication at the interface of the raw material and the tools forming the part. If this lubrication breaks down the frictional forces are very high and parts will begin to stick or "weld" themselves to the working surface of the tooling. The effect is that the first parts to experience this will emerge from the tooling showing signs of damage or incomplete forming and very soon the tool will be subject to breakdown and complete failure.

As noted earlier in the process description, Green Rod emerges from the rolling mill with a rough and often scale encrusted surface. It is critical in the processing of the raw material that this scale and surface detritus be removed. This is usually accomplished by cleaning the coiled rod in hydrochloric or sulfuric acid, although mechanical means of removal can also be utilized. Once clean, however, it must be coated to protect it from any subsequent surface deterioration and to provide the necessary lubrication for forming. There are many coating options and they vary from metal to metal. For example, coatings that work well for steel may not be sufficient for stainless steel, so that normal stainless steel coatings are different than those purchased for carbon and alloy steels. Generally speaking, most manufacturers find a couple of coating variations that they like and have been successful with over the years and stick to these. Whatever they use, however, it is important that they get it right, since insufficient proportions and coverage of coatings will very quickly lead to quality problems and tooling failure.

Improper Microstructure:

The microstructure refers to what is going on inside the metal. There are a complicated array of factors that all must align to provide the optimal performance of the raw material. For this reason, the steel and hot rolling mills employ experts and many safeguards to assure that the final microstructure is correct. Of particular concern will be grain size, spheroidization (from the annealing process of steel) and the amount and size of inclusions. Although these are not the only factors of importance, they are a couple of the more prominent factors that will determine how successful the wire will be in the cold forming process.

Conclusion:

Although most manufacturers likely take the raw material they use for granted, it is a very important and critical component in getting the end product right. In other words, when the raw material exhibits a problem it will surely manifest itself into a bigger problem on finished parts later on. Therefore, manufacturers should have an intimate knowledge of all of their raw material suppliers- the processes they use to manufacturer the raw material, their quality record, and their capabilities. They should actively seek ways to work with their suppliers to provide continual improvement to their raw material and, in doing so, improve their own quality performance. ■