Where Does Cold Heading Wire & Rod Come From?

— Part 1: Steel Making

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Although our human nature is innately curious, we often simply don't have the time to fully explore our world and accept many everyday occurrences at face value. For example, when we flip on a light switch we rarely, if ever, consider how that electricity was generated or delivered to our home. In a similar fashion, those of us who manufacturer fasteners rarely give much thought to how the raw materials we start with are transformed into a product that we can successfully cold head.

This article is the first of a three part series that looks at the origins and processes of cold heading quality wire and rod. Part one explores how steel is created today from both scrap and elemental sources and continuously cast into intermediate steel products. Part two will explore how these intermediate products are "broken down" and hot rolled to form coiled bar and rod. Part three will explore how hot rolled product is further processed into wire and rod that can be introduced and used in a cold header.

The journey must first begin by considering the process utilized in making most threaded fasteners, cold heading. The cold heading process can often be quite extreme and calls on raw material to do more than many other forming processes. As such, this means that the raw material must possess both a consistent and "high quality" composition (or chemistry) and predictable performance. In other words, the material must be able to readily deform without fracturing. This requires steel-making practices that generate a product of high quality with predictable performance characteristics. Material meeting these demanding criteria is known as "cold heading quality" or CHQ steel.

To appreciate the uniqueness of this material, one needs only to understand its place in the market. CHQ wire and rod falls into the steel category known as "long products", which includes all types of wire, structural components and rails. With respect to other varieties of wire, it is one of several other classifications such as Mesh Quality, Industrial Quality, Fine Wire Quality, Bearing Quality and Aircraft Quality. CHQ material, however, constitutes only a very small fraction of this segment and the entire steel market comprising perhaps less than 1% of the total North American production.

Electric Arc Furnace Melting

In North America, almost all CHQ material starts in a "mini-mill" environment using electric arc furnace (EAF) melting technology. This is in sharp contrast to the historical legacy of large, fully integrated steel mills where raw ore entered one side and finished steel products came out the other side. These operations employed large, capital-intensive blast furnace operations that converted raw iron ore to a more pure and usable form known as "pig iron".

In EAF furnaces, the material charge (the materials loaded into the furnace) falls into one of three main categories: scrap, direct reduced iron and pig iron from another mill with a blast furnace. Often a mill will combine these different materials in their material charge. As these sources are even further broken down, one finds that scrap falls into three main categories: shredded material, which is from recycled post-consumer products such as automobiles and old appliances; bushelling, which is from offal of manufacturing processes such as metal stamping trimmings or chips from machining; and in-house scrap or materials generated and recycled during the steel making or hot rolling processes. Direct reduced iron (DRI) is an iron ore product that has undergone a chemical reduction process to convert the iron oxides in iron ore to a relatively pure form of iron. Pig iron is the product of a blast furnace and is also considered a relatively pure form of iron.

For each lot of material (known as a heat), the mill meticulously prepares the furnace charge. Each specific type of steel will have its own combination of starting units. These are layered in the charge receptacle, usually with the denser material towards the bottom and the lighter (or less dense) material at the top. This layering will assist the melting process with the "light" materials melting very quickly, which assists in the melting of the denser items and allows the furnace electrodes to settle into the molten bath more quickly. Dense items would include heavy scrap items such as recycled railroad car wheels, iron rails, structural steel components and pig iron fragments. "Lighter" or less dense material would include shredded scrap, metal stamping trimmings and steel shavings. In addition to the iron components, additions of materials such as lime and dolomite that will make up the slag layer are also added.

When a new heat of material is ready to be started, the furnace electrodes that generate the heat to melt the steel charge are retracted, the furnace is opened and the charge receptacle is positioned overhead. In most cases, the bottom of the charge receptacle splits open like a large clam shell depositing its contents into the furnace. Most often, the furnace still possesses some melted material from the previous heat known as a "hot heel". Not only does this material help foster the melting of the new material, but it also protects the lining of the furnace from the shock of many tons of material being dropped into it. Once loaded, the operator retracts the charge receptacle, closes the lid on the furnace and drops the electrodes into the furnace to begin "arcing", an electrically generated process that passes large amounts of heat energy into the furnace load. Each arc generates massive heat energy, which quickly begins melting the contents of the furnace. As a liquid pool is created and oxygen is added to the bath, energetic chemical reactions begin to take place that generate heat, which works in combination with the electrode arc to melt the remaining unmelted material in the furnace. **Figure 1** shows an electric arc furnace with the electrodes retracted.

Fig. 1 — An electric arc furnace with electrodes retracted.

The furnace operator continues arcing until the entire contents of the furnace are melted. Normally, a second and maybe even third charge of material is added and the process repeated. Once the melting of all the material charged is complete, the furnace is understood to have reached the stage known as "flat bath".

At this stage, the melted material in the furnace is likely to be too high in carbon to yet be considered steel. Therefore, the refinement process begins with the furnace operator injecting or what is called lancing the bath with oxygen to lower the carbon content to the desired levels for tapping (or the process of removing the molten bath from the EAF). This sets off a frenetic reaction within the molten steel bath because the oxygen has a high affinity for many of the bath components including aluminum, silicon, manganese, phosphorous, carbon and iron. The carbon is released in the form of carbon monoxide (CO) and becomes a critical player in the refining part of the EAF melting process.

The reaction of carbon and oxygen to form CO is highly exothermic (the reaction gives off heat) providing the furnace an efficient and inexpensive supply of heat. Since CO is a gas, its evolution in the bath creates bubbles that result in a "foaming" of the slag, which serves to help in burying the arc providing improved thermal efficiency and protection against exposing the arc to nitrogen that can lead to unwanted absorption into the steel. Finally, the CO helps to reduce the nitrogen and hydrogen levels in the steel. This is particularly advantageous as the presence of these elements is unwanted in higher concentrations. In addition to generating CO, the oxygen will also react with other components in the bath to form oxides. These oxides are lighter than the steel and float out of the steel into the slag layer.

At the same time that the carbon content is being lowered, other unwanted products, specifically sulfur and phosphorous, are being addressed. Unfortunately, the conditions that assist in the removal of sulfur are nearly opposite those required for the removal of phosphorous. Therefore, the furnace operator must strategically tackle this problem by taking intentional steps to exert control when the conditions are most favorable in the process, or, and this is perhaps more often the case, the removal of one of these elements is targeted in the melting and the other during ladle refinement stages, respectively.

Phosphorous removal is dependent on several conditions, one of them being low bath temperature. Therefore, the process of dephosphorization often happens early in the process when bath temperatures are lower. Once the phosphorous is trapped in the slag, a deslagging (or slag removal from the furnace) process occurs where the slag is poured out of the furnace. This is important because as conditions change, it is possible that the phosphorous can revert back into the bath. However, if the phosphorous rich slag is removed from the furnace, it is impossible for this to occur.

Sulfur is primarily removed when sulfides are trapped in the slag. With today's melting practices, achieving removal is complicated and often quite difficult. Therefore, it is common that desulfurization occurs either during the tapping or ladle refinement operations when the slag chemistries and conditions are different and more favorable than during EAF melting.

Although the casual observer might consider this slag layer to serve no other purpose than to collect the refuse or unwanted parts of the steel bath, in reality it does a great deal more. It does in fact act like a chemical sponge to attract and trap certain unwanted constituents, particularly phosphorous, sulfur, silicon and manganese. However, it also protects the molten steel bath from absorbing or reabsorbing unwanted or deleterious constituents, in particular, nitrogen. Normal atmospheric air is full of nitrogen that can be drawn into the steel melt from the surrounding mill environmental. Fortunately, the slag layer acts like a one way barrier, drawing unwanted items out of the bath but not allowing them to pass back in.

The furnace operator closely monitors the composition of the steel bath and its temperature. Once the bath reaches the desired levels for the particular steel or alloy being produced, the furnace is ready to be tapped. Practically speaking this is the process of emptying the bath into a new receptacle known as the ladle, which is appropriately named for it is simply a large "cup" that receives the molten steel for further refinement and later to be poured out for casting (see **Figure 2**). Normally the furnace is tapped down low to minimize the reabsorption of unwanted constituents such as nitrogen. Also, the mill will commonly deoxidize the steel at this point by adding silicon or aluminum in a process known as "killing the steel". Although this is the stage where deoxidation usually occurs, for some continuous casting operations, the addition of aluminum for deoxidation creates challenges at the caster, so that this practice is actually accomplished there instead of at tapping of the EAF. A new slag layer is developed at this stage as well.

Fig. 2 — Tapping EAF into ladle.

Ladle Refinement

Once the steel bath is tapped from the EAF, it has made considerable progress on its course of becoming a specific grade or type of steel.

However, before it is complete there is still some fine tuning required. This is accomplished at the Ladle Refinement or Ladle Furnace stage. This process is analogous to a master chef preparing his house specialty. Early on, he will add ingredients like salt and spices in coarse proportions, which he knows will give the taste blend he is looking for, but he will not serve the dish without first tasting it and making some final adjustments to the levels of these ingredients to bring it to perfection.

In the Ladle Refinement stage, the operator takes samples of the bath and sends them to the on-site lab to gain a precise knowledge of the make-up of the bath. With these results in-hand, a computer is able to analyze the results and determine the necessary additions required to obtain the desired steel type. The computer will provide precise details regarding the amounts and types of constituents that need to be added to obtain the desired alloy blend. The operator will then add these materials through portals into the Ladle Refinement Furnace. This practice is often called "trimming" or making "trims" to the bath.

In addition to making these trims to get the composition levels right, this stage allows the mill to perform additional refinement to the bath. As mentioned earlier, it is very common for desulfurization to occur at this stage. Additionally however, this operation usually injects an inert gas such as argon to help float additional inclusions and oxides into the slag layer as well as assisting in homogenizing the steel's chemistry and temperature.

Although not every producer includes this, many producers either do some or all of this ladle refinement under vacuum. This is referred to as a vacuum degassing process and primarily is used to further lower concentrations of hydrogen, nitrogen and oxygen in the bath. It also assists in providing favorable conditions for desulfurization. Steel that has undergone this process can be expected to be of higher quality than material that has not.

Continuous Casting

In former times, steel was poured into large stationary molds producing what is known as an ingot. Today, continuous casting allows each heat of steel to be poured into a caster creating one or more continuous strands of steel billets, blooms or slabs (these terms generally refer to the size and shape of the cast product). A slab is broken down to provide flat stock material, but either a billet or a bloom (difference is in the cross sectional size with a bloom being the larger) can be used in the subsequent hot rolling process to produce cold heading rod or bar. The advantages of this process include improvements in productivity, quality and cost.

Although the process is relatively technically sophisticated, it is relatively simple in concept. The ladle is moved from Ladle Refinement and positioned above the caster. The ladle is tapped and empties into a large trough like receptacle known as the Tundish. At the bottom of the Tundish is an outlet for each strand in the casting line. So for example, a four-strand line will have four openings in the Tundish (see **Figure 3**). The molten steel enters these openings and goes through a water jacketed mold where the outside is sufficiently cooled to create a solid shell.

The steel exits cast in the shape of the mold and pro-

Fig. 3 — Inside view of the Tundish.

Fig. 4 — Six-strand continuous casting line.

gresses down along a gently radiused track (**Figure 4**). As the cast shape moves further away from the mold, it continues to cool and solidify throughout. The track gently transitions to a fully horizontal conveyor which each strand progresses along. Once the strand has reached a mill specific length, a torch cuts the strand forming the billet. Each newly formed billet or bloom is conveyed along a track to a point where all the different strands are consolidated. The mill takes great care to maintain identification and traceability of each billet or bloom and is able to identify the strand and order each billet or bloom was manufactured in. After identification is placed on each billet or bloom, they are removed, left to cool, and ready for the hot rolling operation.

Summary

Turning scrap and iron units into a finished steel billet or bloom is a fascinating and critical step in the journey of making a steel fastener. This article has explored the basic principles of how the steel making process starts in an electric arc furnace, undergoes refinement and ends up creating an intermediate steel product known as a billet or bloom. Every step in the journey is important, but this one especially so, since the quality and consistency of the steel will in many ways define the fasteners produced from it at the end of the process.

In Part 2 of this series, we will explore how these billets are broken down from the 5" or 6" square shapes (or similarly equivalent other shapes and sizes) that they are in and formed into the coiled round shape that fastener manufacturers are accustomed to working with.

We will learn however, that even though the material begins to resemble the raw materials used in our manufacturing, this is still an interim step and additional processing to be discussed in Part 3 is required.

To learn more, visit the website listed below.

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Reference:

[1] *Jones, Jeremy, A.T., "Electric Arc Furnace Steel making", Steelworks, the online resource for steel, American Iron and Steel Institute, Washington DC, 2013.*

Company Profile:

***NNI Training and Consulting Inc.**, headquartered in Green Oaks, IL, USA, is a dynamic, entrepreneurial 'knowledge provider' that provides training and consulting services to small and medium-sized companies. The company's specific expertise is in cold heading, fasteners, fastener and application engineering, and automotive, industrial and aerospace parts supply. NNI Training and Consulting Inc. provides training that is based on a strong foundation of theoretical knowledge, which is combined with practical understanding and applied skills. NNI Training and Consulting Inc. provides its customers with consulting services on fasteners, fastener engineering and fastener quality; quality management systems and certifications; and business and sales development and strategy. Offering customers an unbiased perspective, technical expertise, solid business acumen, new ways of doing things and keen insight are the specialties of NNI Training and Consulting Inc. To learn more about the company, visit the website listed below.*

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