



Current State of Fire Refined High Conductivity Copper Rod from a Producer's Perspective

Fire refined high conductivity (FRHC) copper rod was brought to the modern American market in 2012. At the time, FRHC rod was generally considered a low-cost and low-quality alternative to electrolytic tough pitch (ETP) rod. Many would draw direct comparisons between FRHC rod and the wire bars of the early 20th century. Advances in feedstock control, furnace technology, refining, and casting have positioned today's FRHC rod to compete directly with ETP on material properties while outperforming it on sustainability metrics. This paper will examine the differences between COPPERWORKS™ FRHC of 2012-2015, COPPERWORKS FRHC produced today, and ETP rod. The data presented was collected on ETP and FRHC rods produced on the same casting and rolling machine. A direct comparison of the materials will present the capabilities achievable with fire refining by applying the advances of the past 14 years.

ROD PROPERTIES

In the American market, copper rod is often produced in accordance with the American Society for Testing and Materials (ASTM) B49-20 Standard Specification for Copper Rod for Electrical Purposes. This specification covers electrolytic tough pitch (ETP), oxygen free electronic (OFE), oxygen free (OF), and fire refined high conductivity (FRHC) rod. Oxygen free electronic and oxygen free will only be discussed in terms of the relative requirements of the standard and no attempt will be made to discuss the relative performance of the material due to a lack of material test results. Within B49, 6 Unified Numbering System (UNS) designations are identified, 2 for each type of copper. Each type, ETP, OFE/OF, and FRHC, has a general chemistry requiring a minimum copper concentration inclusive of silver and a specific chemistry. Each specific chemistry details maximum allowable levels or allowable ranges for individual elements. These specific chemistries are the largest difference in copper types. Maximum allowable limits for individual elements are higher for FRHC as compared to both ETP and OFE. The general UNS identifiers are identical for ETP (UNS C11000) and FRHC (UNS C11020), and the general chemistry for OF (UNS C10200) requires an additional 0.05% increase in copper purity and calls out a maximum oxygen content (ASTM International, 2020). While the specific chemistry requirements do offer significant differences in ETP, OFE, and FRHC rod, **compliance with the chemistry standards does not guarantee rod performance.** The ability to produce suitable rod outside

the chemistry specifications and sub-standard rod within the chemistry specification is part of the reason why ASTM and other standard organizations also have specifications for material properties. The rest of this discussion will focus on the material properties of ETP and FRHC rod. For many wire manufacturers, the performance characteristics and processing behaviors of the copper rod matter more than its UNS designation. ASTM, and other standard organizations, use material properties as facsimiles for processability, notably electrical resistivity or conductivity, elongation, surface oxidation, diameter, and shape. Regardless of the copper type or UNS number, these are all considered and evaluated uniformly by ASTM. Therefore, any performance differences cannot be evaluated using solely the standards applied to each copper type, but instead must be evaluated by measured material properties. One of the primary material properties for copper rod is electrical conductivity. ASTM requires a minimum conductivity of 100.0% International Annealed Copper Standard (IACS) for both ETP and FRHC rod (ASTM International, 2020). While this is a minimum standard that must be met, both ETP and FRHC rod are regularly produced and sold at higher conductivities. It is not uncommon for ETP rod to have an electrical conductivity of 101.0-101.5% IACS. The FRHC rod produced by COPPERWORKS from 2012 through 2024 ranged from 100.0-100.8% IACS, with fluctuations in that time period.

In 2024 and into 2026, efforts were made to apply the 12 years of process knowledge acquired to increase the conductivity of FRHC rod. The result of these efforts was a significant and consistent increase in conductivity until COPPERWORKS was able to consistently produce FRHC rod with electrical conductivity of over 101.0% IACS. A graphical representation of the conductivity of FRHC rod produced by COPPERWORKS throughout the years can be found in **Figure 1**. This shows the average conductivity for all FRHC rod produced by year. For wire producers, this results in improved wire performance and conductivity. The other material properties defined in ASTM B49 are diameter, elongation, and surface oxide thickness. While the standard is the same for ETP, OFE, OF, and FRHC rod, significant variation between the materials within the specified limits could result in marginal performance differences.

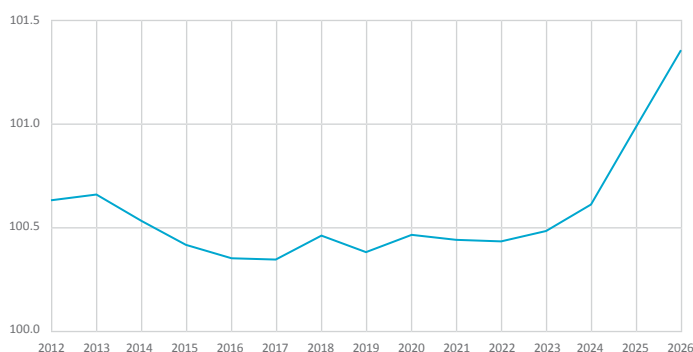


Figure 1: Annual average conductivity (%IACS) of FRHC rod produced at COPPERWORKS through February 2026.

Summary data for the 2025 production of ETP and FRHC rod at COPPERWORKS is shown in **Figure 2**. The consistency across copper type highlights the extent to which material properties are dependent on casting and rolling, not copper type. Elongation is a likely candidate

to see a difference by material type. Trace elements in significantly elevated concentrations would modify the as-cast metallurgy, impacting the tensile properties of the rod. In practice, the trace element levels in FRHC rod are so minimal that there is no practical difference in the elongation as it is measured. Surface oxidation is similar to elongation in that after controlling trace element levels in FRHC rod, rolling practices are the driving factor. Thus, as is the case at COPPERWORKS, the same producer will have ETP and FRHC rod with similar if not identical surface oxidation values. This is further supported by the uniform distribution of elevated surface oxide levels between ETP and FRHC rod. With proper understanding and control of the trace elements that can be present in FRHC copper, it is possible to eliminate potential quality risks. The same elements that can impact FRHC rod can be found in low grade copper cathode or as point contamination found between the sheets of cathode. Electrolytic tough pitch rod is susceptible to the same impacts on quality without proper inbound material control.

DRAWING PROPERTIES AND ADDITIONAL CONSIDERATIONS WHEN DRAWING AND CABLING FRHC

The material properties of copper rod are a mere facsimile for the ability of the rod to be drawn into wire and cable assemblies. Originally, COPPERWORKS FRHC rod was used almost exclusively for large diameter wire, and mostly for building wire applications. Currently, FRHC rod is being drawn down to wire finer than 32 AWG and is used in alarm and irrigation wire, automotive wire, building wire, data cables, power transmission cables, and utility cables. Rod related issues that would result in wire breaks during the drawing process for ETP can be present in FRHC.

	FRHC			ETP		
	Min	Average	Max	Min	Average	Max
Diameter (mm)	7.79	7.97	8.21	7.79	7.98	8.35
Elongation (%)	34	39.8	49	32	39.4	46
Surface Oxide (Å)	12	95.2	574	12	85.5	551

Figure 2: Table summarizing the 2025 production data for both FRHC and ETP rod at COPPERWORKS.



The reality is that these are not chemistry problems, but rather casting and rolling defects. As these defects are not related to the material itself, they will not be discussed in depth here. There are some specific casting and rolling defects in which elevated trace element levels increase the likelihood of occurrence. Once a producer understands the source of these defects, the FRHC process is unique in its ability to control and reduce impurity levels. The nature of producing ETP rod is that the rod chemistry is determined almost solely by the cathode that is charged to the furnace. There is no opportunity to modify or refine the metal once it is charged to a vertical shaft furnace to produce ETP. Most notable among the casting and rolling defects that can be more prevalent without proper chemistry control is slivers. Select trace elements increase the propensity of copper to form slivers during hot rolling. Elevated levels of trace elements are only one potential source of slivers on copper rod and control of casting and rolling practices is also required to prevent the formation of slivers. There are processing differences in ETP and FRHC as they are produced into wire. The increased trace elements in FRHC rod do increase the recrystallization temperature slightly, resulting in more power demand during the annealing process. Increased annealing power requirements shifts the annealing curves associated with property recovery after cold working in the drawing machine as seen in Figures 3-5. The data presented below represents drawing ETP and FRHC rod on a rod breakdown machine. As can be seen in **Figure 3** the power required to recover elongation above 30% for FRHC is more than ETP. There is a difference of 10 kVA/ton to reach the upper plateau on the annealing curve for elongation. Similar shifts can be seen in the annealing curves showing the recovery in conductivity

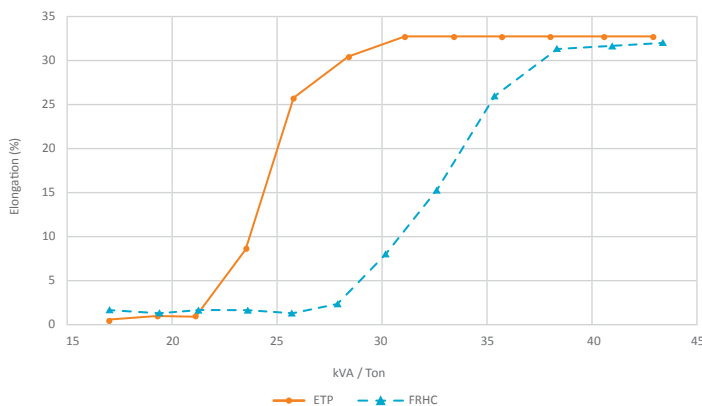


Figure 3: Annealing curve representing summaries of multiple tests for both ETP and FRHC copper being drawn from 8mm to 9 AWG wire.

and tensile strength as shown in **Figure 4** and **Figure 5**.

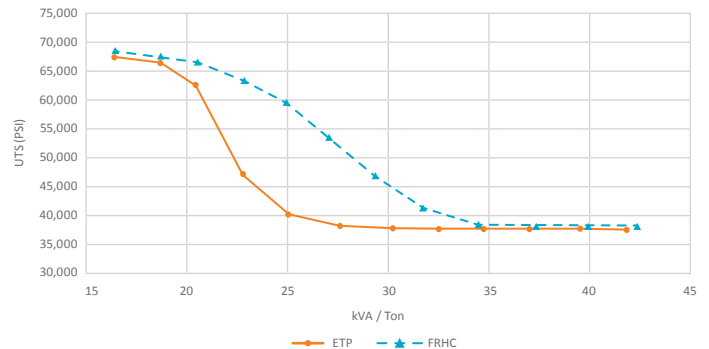


Figure 4: Annealing curve showing the softening of wire and decline in tensile strength until the fully soft state is reached.

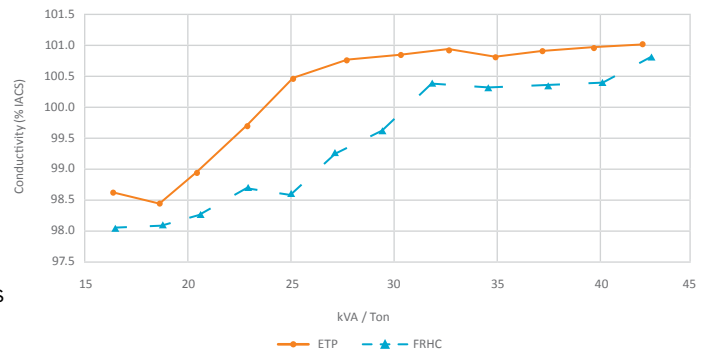


Figure 5: Annealing curve showing the conductivity recovery of wire as it is annealed.

Tensile strength recovery showed the same 10 kVA/ton difference between ETP and FRHC as with elongation. While the power difference to reach the fully soft state is of interest for any wire requiring a minimum of 30% elongation, there is a noteworthy shift in the shape of the curve for FRHC as compared to ETP. The transition from fully hard to fully soft is more gradual in FRHC than ETP. For the unique situation where retaining some tensile strength is more important than greater levels of elongation, this produces an opportunity to more easily achieve the desired wire qualities. Electrical conductivity has a similar though less severe power shift between FRHC and ETP. When considering conductivity, the power shift is reduced to only 4 kVA/ton compared to 10 kVA/ton for elongation and tensile strength. While the annealing power is a significant part of wire



production, it is not the only power consumption to consider. Before making a true comparison of the power required to produce wire, it is important to consider the end-to-end power requirements of the entire wire processing line. While annealing FRHC rod may require additional power, the actual drawing step does not, thus the total power increase is significantly less than would be implied if only the annealing curves were considered. **Figure 6** shows the total power demand to produce nominally 0.0540 inch diameter wire across 2 lines. In this instance, for ETP, 249 kW hr/ton is used in the drawing machine, while 136 kW hr/ton is used in the annealer. This shows that approximately only 1/3 of the power consumed is in the annealer. For this instance, the total power consumed to produce ETP rod is 385 kW hr/ton and 435 kW hr/kg for FRHC. That yields a total power increase to produce FRHC wire of only 13% as opposed to the nearly 30% increase if only the annealing component of the process was considered.

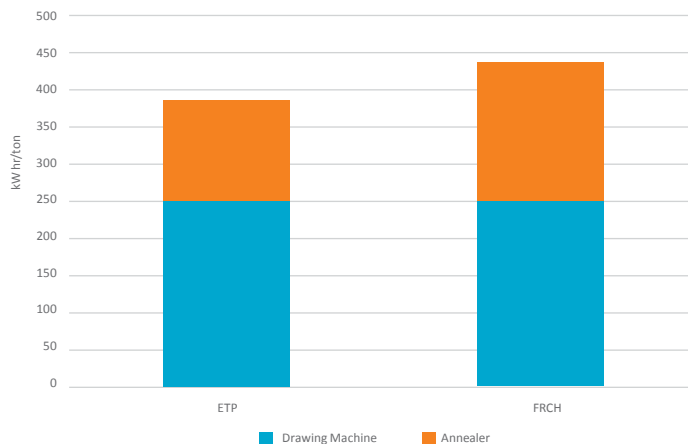


Figure 6: Total power consumption to produce two lines 0.0540 inch diameter wire on a drawing machine.

ENVIRONMENTAL IMPACTS

Today, there is a growing desire for low environmental impact materials and sustainable manufacturing. This is being felt up and down the supply chain across nearly all industries. For the copper wire and cable industry, FRHC rod is one of the simplest and most reliable solutions for long term environmental impact minimization. FRHC can be produced using up to 100% recycled materials, and there are significant implicit environmental impact reductions as compared to rod produced from copper cathode. Several mining companies are working to develop or launch low carbon or low impact cathode processes. Most of these are reliant on reducing the emissions from extraction and refining. These technologies can provide significant reductions as compared to current mining practices, but do not eliminate them. The cathode retains those emissions and is carried through as scope 2 emissions at the rod mill. Other groups are avoiding the emissions associated with extraction by converting scrap material into anodes and refining from there to produce copper cathodes. While this does offer reductions as compared to traditional ore extraction, the molten refining process followed by electrolytic refining still has additional emissions as compared to direct molten refining to rod production. Empirically, the total emissions associated with producing ETP and FRHC rod can be directly compared using COPPERWORKS' environmental product declarations (EPD).

Figure 7 and **Figure 8** show side by side comparisons for ETP and FRHC rod on a cradle to gate basis as produced at COPPERWORKS. FRHC rod as a base material offers over a 90% reduction in eutrophication, acidification, and smog formation potential as well as freshwater consumption. Ozone depletion potential has an 89.7% reduction when using FRHC as opposed to ETP. Global warming potential or carbon emissions FRHC offers a 73.7% reduction when compared to ETP rod. The complexity and amount of detail in environmental impact reporting prohibits an in-depth explanation of impact classification here. The minimal wire drawing process differences allow for very similar values to be carried through for wire production. The extent of the differences in wire production will be dependent on the proximity of the rod mill for ETP and FRHC to the wire producer as well as the individual wire producer's utility impact. Due to the producer dependency, the net impact of choosing FRHC rod over ETP rod on the wire drawing facilities scope 2 emissions will not be discussed here.

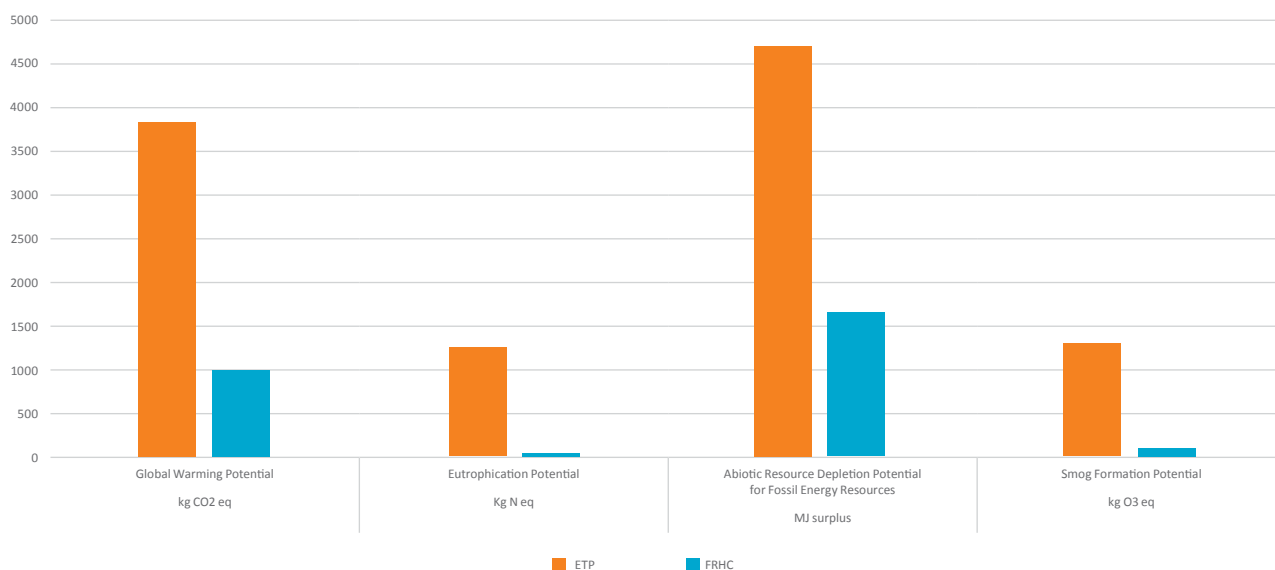


Figure 7: Graphical representation of select total environmental impact measures for ETP and FRHC Infinity rod produced at COPPERWORKS. This data represents cradle to gate values for one metric ton of copper using values from production in 2021.

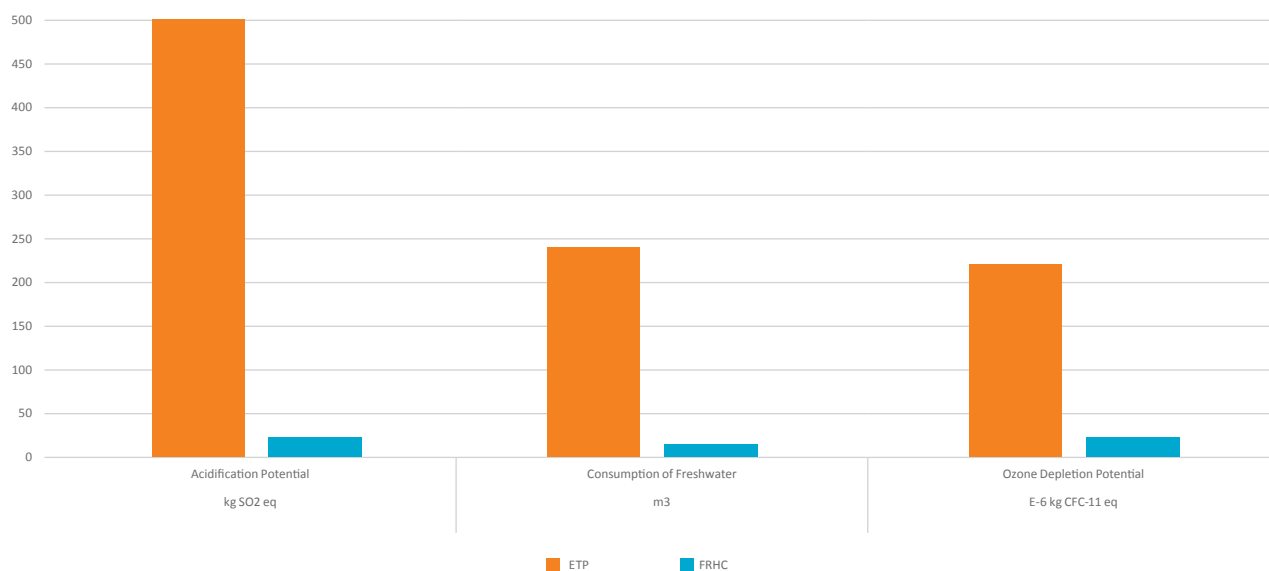


Figure 8: Graphical representation of select total environmental impact measures for ETP and FRHC Infinity rod produced at COPPERWORKS. This data represents cradle to gate values for one metric tonne of copper using values from production in 2021.



FUTURE DEVELOPMENT OF THE MATERIAL

Modern FRHC rod offers significant improvements over the material that was introduced to the American rod market in 2012. As it stands, FRHC rod can offer comparable electrical properties and drawability to ETP rod with the opportunity for significant environmental and sustainability advantages. Modern FRHC rod still requires additional annealing power to achieve the same properties as ETP after cold working, but the end-to-end power requirements of the entire wire processing process are similar. COPPERWORKS has begun the next stage of FRHC development to narrow the annealing power difference. As shown in **Figure 9**, this new wave of FRHC in preliminary testing has reduced the power difference by more than 25%. While this work is showing promise, efforts continue to reduce the power difference. The extent to which annealing power can be reduced in FRHC is still being determined.

CONCLUSION

Over the past century, copper rod production has evolved through three major transitions: from wire bars to continuously cast rod, from blister copper to electro-refined cathode, and most recently, the emergence of FRHC rod. In the American market alone, FRHC copper has transformed over the last 14 years — from a low-cost, low-quality option to a viable ETP alternative capable of being drawn to sizes smaller than 32 AWG. Just as the integration of continuous casting with hot rolling was a defining inflection point for the industry in the 20th century, the refinement of FRHC copper stands as its equivalent for the 21st.

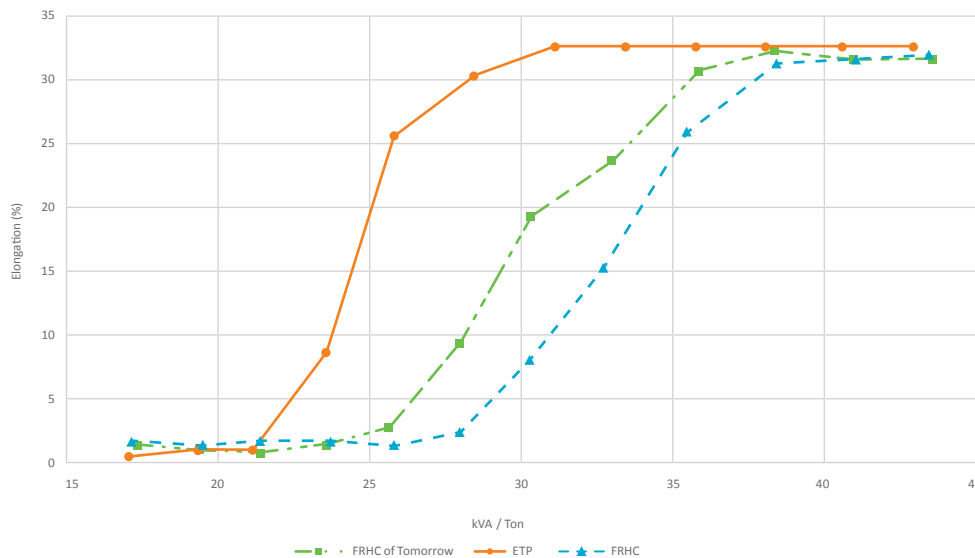


Figure 9: Annealing curve for elongation of 12 AWG wire showing ETP, FRHC, and first release of future FRHC.

REFERENCES

ASTM International. (2020). ASTM Standard B49, 2020, "Standard Specification for Copper Rod for Electrical Purposes". West Conshohocken, PA.