THE EFFECTS OF STEEL MILL PRACTICE ON PIPE AND TUBE MAKING

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The effects of chemistry, melting, casting, and rolling on slitting, forming, welding and heat treating are highly complex and inter-related . This paper is not meant to be an exhaustive discussion of each variable upon the others but rather to show examples of steel mill practices and how they can affect the production of pipe and tube.

STEEL MAKING METHODS

Modern steel making has evolved toward two basic forms of melting: Electric Arc and Basic Oxygen. Only a brief description of each will be offered since the specific details of each go well beyond the scope of this paper. Electric Arc furnaces are large, refractory lined vessels with a removable roof (Fig 1). To charge the furnace, the roof is moved out of the way and scrap metal is loaded in. The roof is replaced and an electric current is passed through electrodes extending through the roof into the furnace. The current passes from one electrode through the scrap charge and back to the other electrodes. The steels resistance to the electric current generates the heat to melt the scrap.

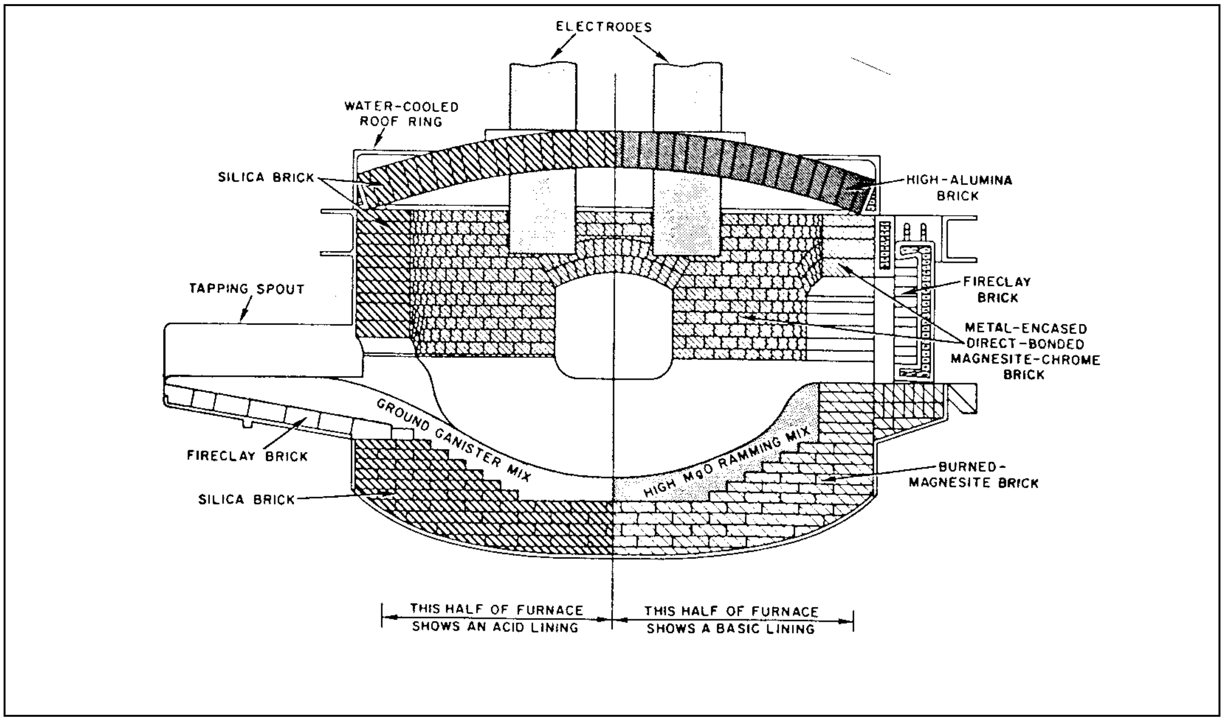


Fig 1 Schematic of Electric Arc Furnace

When the scrap has been fully melted, the furnace is tapped into a ladle. Since scrap is used for 100% of the charge, no blast furnace is needed making the EAF is very suitable for mini mills. However, since each mill generates and re-melts some scrap of its own, residual elements such as Chromium, Nickel, Molybdenum, Vanadium, etc., tend to build up over time and the influence of residuals can be very significant in pipe making.

The Basic Oxygen process (Fig 2) utilizes molten iron produced in a blast furnace. This molten iron is poured into a BOF vessel and scrap, iron ore, and flux are added. An Oxygen lance is inserted into the BOF and high pressure oxygen is blown in.

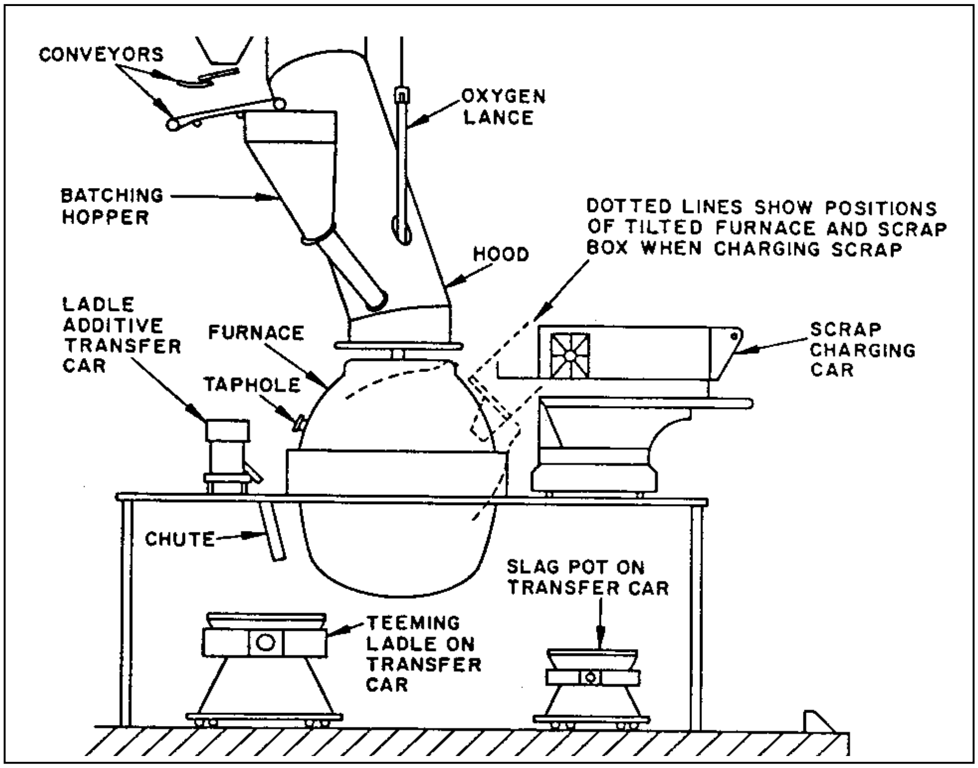


Fig 2 Basic Oxygen Furnace

The resulting reaction raises the temperature of the melted iron and further melts the scrap. The carbon level of the molten iron is reduced to the desired level and the metal is tapped into a ladle. Since very little scrap is added to each heat, the residuals for BOF are very low compared to EAF steel.

STEEL CASTING METHODS

Ingot casting has for many years been the mainstay of steel production. This method involves pouring the molten steel into refractory lined ingot molds, sealing the top to hold in heat and allowing the steel to solidify into an ingot (Fig 3). Ingot size varies with the size of the final product to be produced but generally are in the 10-50 ton range. It may take several days for the ingot to solidify, after which the ingot is stripped from the mold, reheated, the top cropped, and the ingot rolled into its final product shape.

Because the ingot takes so long to solidify, the resulting solid is not very homogeneous with regard to chemistry and microstructure. The last part of the ingot to solidify is the center, and, therefore, the center tends to have a higher concentration of alloy elements and impurities. Even after rolling, the center will exhibit this positive segregation. The segregation can affect slitting and welding practices as we will discuss later.

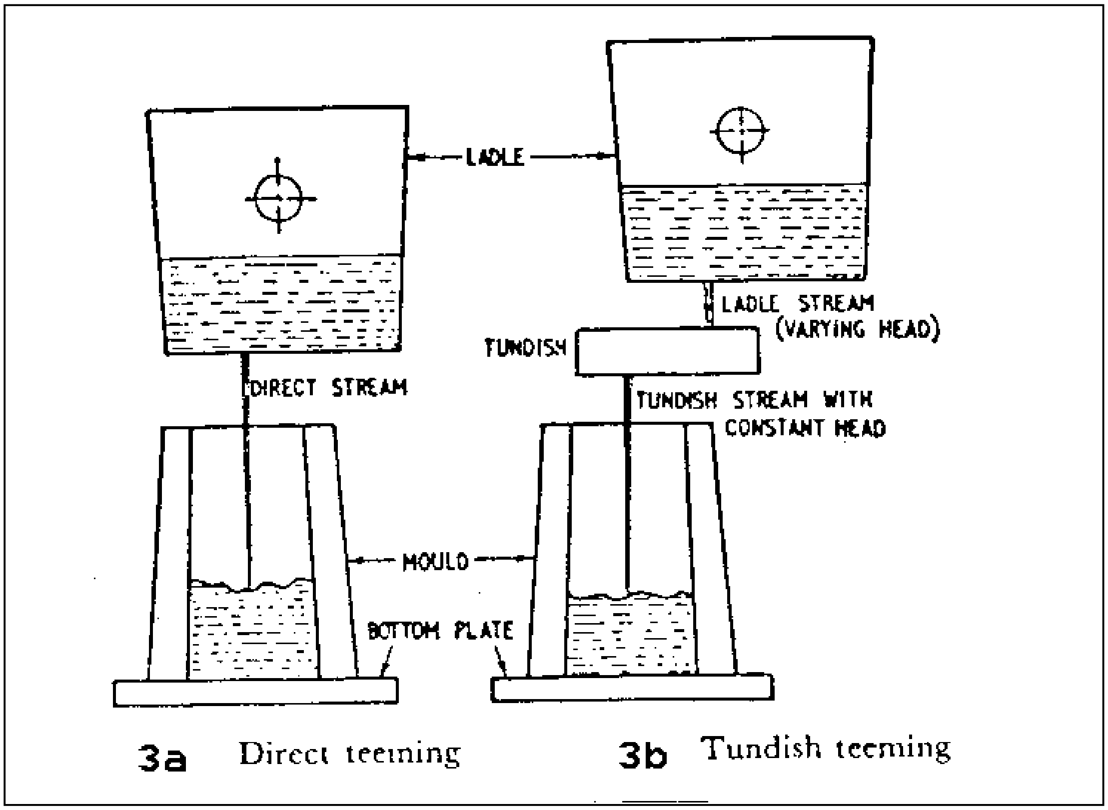


Fig 3. Schematic of Ingot Casting Method

The most modern method of casting steel is the Continuous method (Fig 4). Molten steel is poured into a ladle as in ingot casting but instead of teeming into ingot molds, it is poured into a tundish which provides a steady stream of metal to the caster. In the caster, the molten steel forms a solid skin very quickly as it is allowed to progress slowly down the caster cavity.

As it exits from the caster, it is solid throughout and is cut off in lengths appropriate for the product to be produced, The caster has two great advantages. First, it accelerates the cooling rate of the metal thus reducing the time required for solidification. Second, the cast slab is closer to final shape and does not require as much rolling to get a finished product.
The fact that the cooling rate is faster means that the segregation is much reduced making a more homogeneous final product. The caster also produces a much improved surface condition which results in fewer lap, seams and slivers.

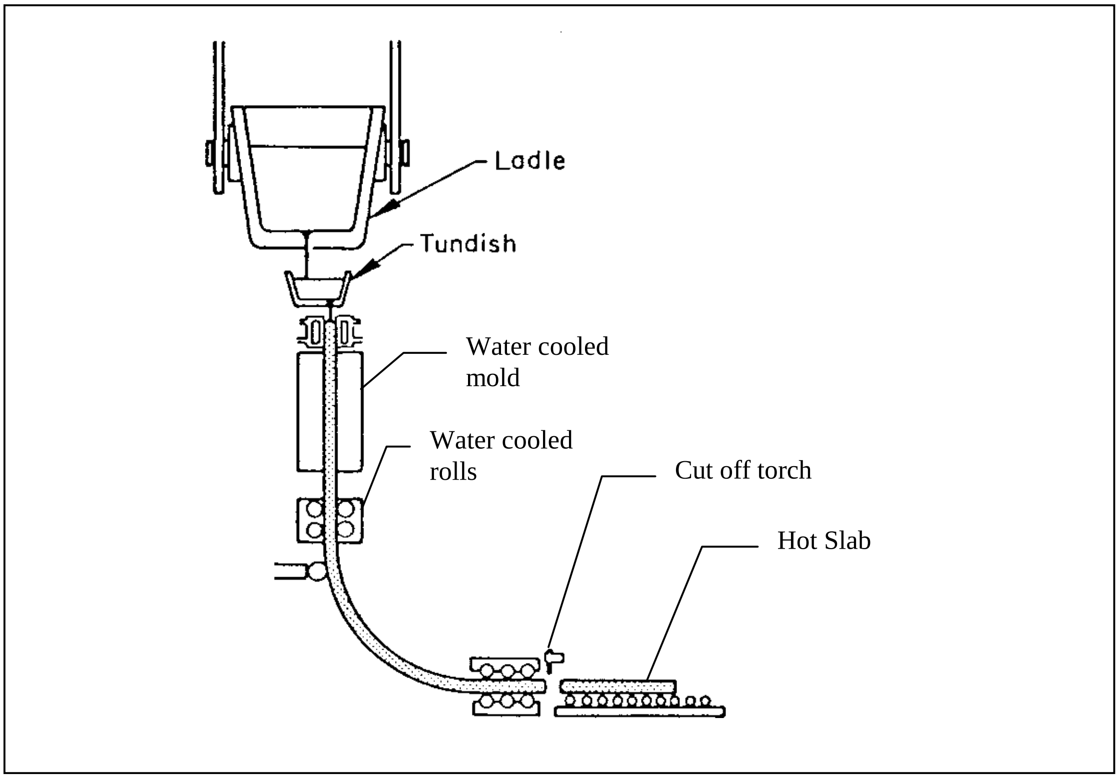


Fig 4 Schematic of Continuous Slab Casting Method

STEEL ROLLING METHODS

There are two basic methods of hot rolling steel skelp, either by a continuous process or by a reversing process. There are many variations of each process so we will discuss them only schematically.

In the continuous process (Fig 5), a steel slab is re-heated in a furnace to the rolling temperature and fed into a series of roll stands where each succeeding set of rolls reduces the thickness until it exits the final stand at finished gage. This is the fastest method and usually results in less surface scale and better gage control. However, it is very time consuming to set up the mill and is usually economical only on relatively large tonnage runs.

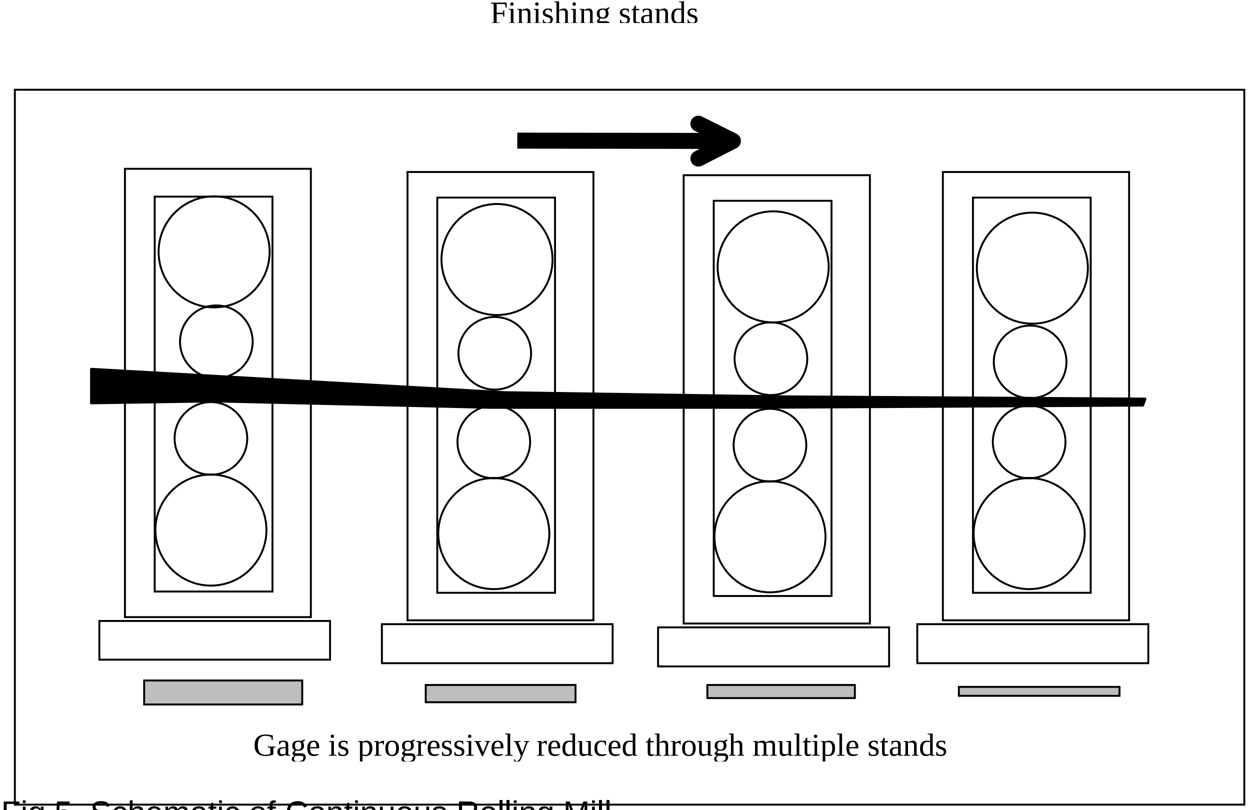


Fig 5 Schematic of Continuous Rolling Mill

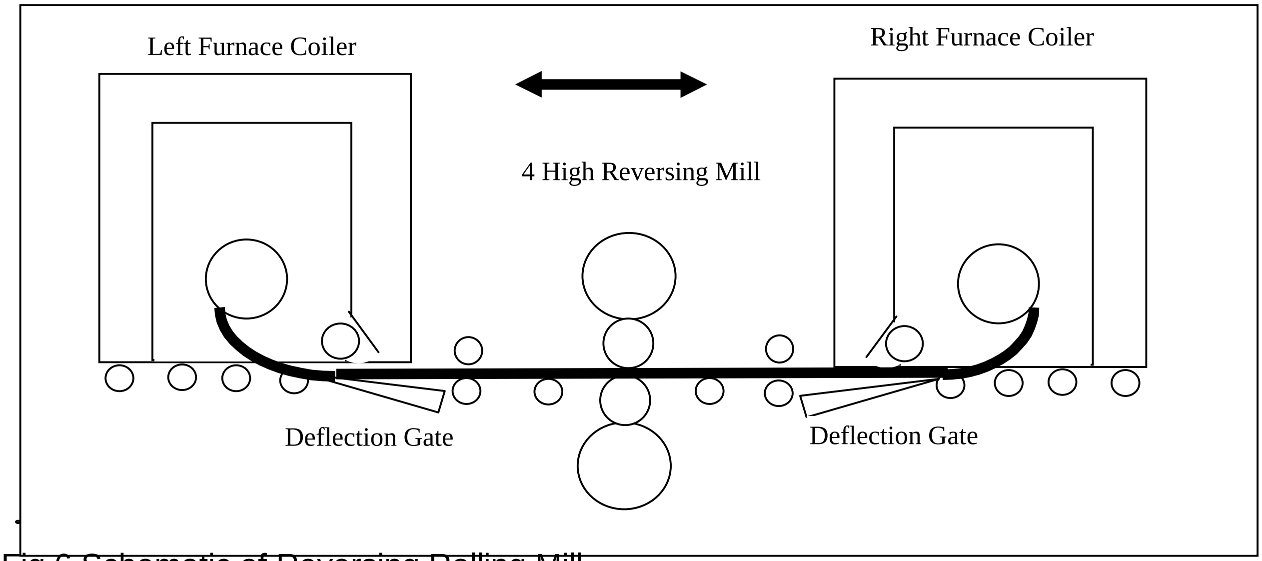


Fig 6 Schematic of Reversing Rolling Mill

The reversing process (Fig 6) utilizes only one set of rolls which can be moved closer together after each succeeding pass and the steel skelp is passed back and forth through the rolls until it is reduced to the desired gage. The reversing process is very quickly adjusted to new gages but takes longer to process each coil of steel. The result is that more scale is developed on the surface of the steel. Also, because the rolls are less rigid than the continuous mill rolls, gage control is not quite as good.

CHEMISTRY

Of all the elements added to iron, carbon is the most influential (Fig 7). It is the main strengthening element as well as the most potent hardening element. The higher the carbon, the greater the strength and hardness (Steel is defined as having less than about 2 % carbon, over this and it becomes cast iron). The higher the carbon content, the more complicated the welding becomes because of the tendency of high carbon steels to crack when heated and cooled rapidly (as in welding).

CARBON: .08% TO .30%
MANGANESE: .20% TO 1.00%
SILICON : .15% TO .35%
PHOSPHORUS: .040% MAX
SULFUR: .03% MAX
ALUMINUM : .03% TO .06%

Fig 7 Typical Carbon Steel Chemistry

Manganese is a vital element in steel making in that it contributes to the strengthening and facilitates hot rolling without hot shortness (melting along grain boundaries due to sulfur). It tends to segregate readily along with carbon and also forms Manganese sulfides (stringers) which are associated with hook cracks near the weld.

Sulfur is an impurity which is introduced into the steel during the melting process from the ore and from fuels used to process the molten metal. It is usually kept below .03% and in many modern steel mills can be reduced to .002% Lower sulfur contents produce cleaner steel with fewer hook cracks and flat test failures. Phosphorus is also an impurity which must be kept below about .04%. Both sulfur and phosphorus tend to segregate and even though the average melt analysis for these elements may be within specifications, localized segregate bands may contain significantly more.

Silicon and Aluminum are added to steel to "kill" the evolution of gasses after the molten steel has been cast. They both act to retard grain growth of the solid steel but high silicon contents are thought to promote some types of weld defects. Aluminum is the most potent of the two with respect to controlling grain size as well as being a very effective deoxidizer.

EFFECTS ON PIPE AND TUBE MAKING

While we have not dealt with the above topics in any great detail, each process we have discussed has a unique effect on slitting, forming, welding, and heat treating.

SLITTING

The slitting of hot rolled carbon steel can create significant problems for the welder if the resulting edge is not straight and square with minimum burr. Ingot cast steel will tend to segregate towards the center of the ingot (Fig 8) and when rolled into skelp, the center of the skelp retains the bulk of impurities. When skelp is center slit, the two inner edges will usually contain significantly more inclusions, laminations, and hard spots than the outer edges (Fig 9. The center slit edges of ingot cast steel is more likely to exhibit shelving and bad profiles (Fig 10). Continuous cast steel has less center segregation and will generally not exhibit as many center slit defects.

When steel is rolled on a continuous mill, gage control is somewhat better due to the rigidity of the rolls and stands. This means that crown is less and edges are more uniform than for reversing mill product. The result of this is the edges of multi-slit skelp are nearly the same thickness (Fig 10) resulting in straighter and more uniform slits. Also, the lead and trail ends of continuous mill skelp are less likely to be thicker or thinner than the center. This is not to say that reversing mills cannot produce a product which is usable for many applications. We are only pointing out that for certain applications, some methods of rolling work better than others. Generally speaking, the more uniform the microstructure and dimensions, the more uniform will be the slit edges. This in turn will result is better and more consistent weld quality

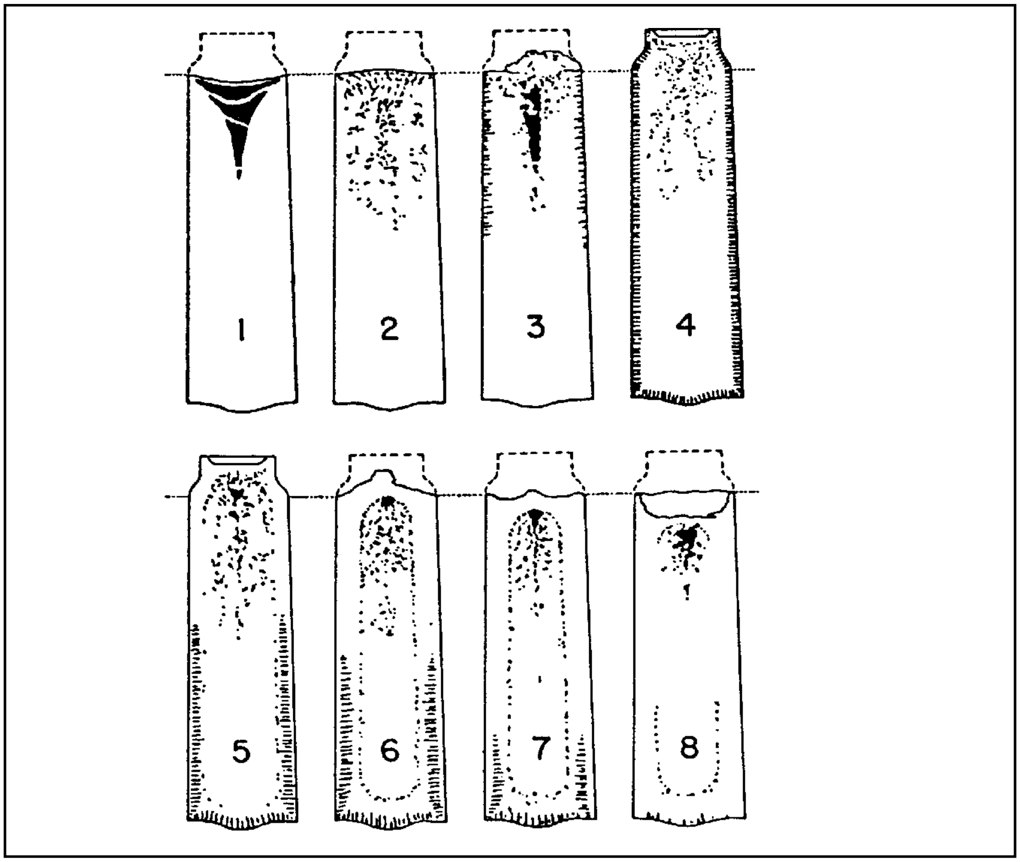


Fig 8 Ingot Segregation

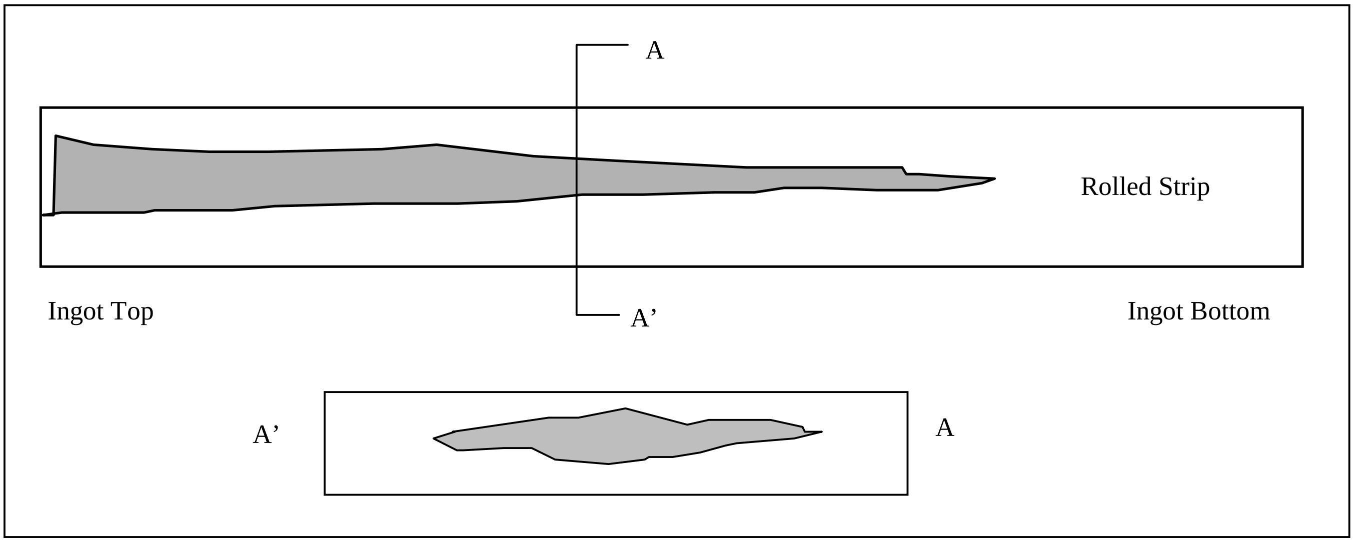


Fig 9 Segregation in Strip

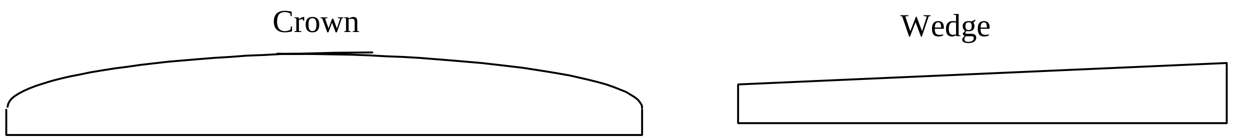
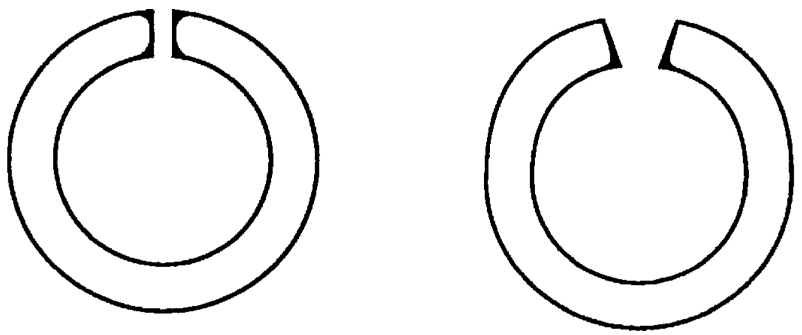


Fig 10 Gage variation in Strip

FORMING

Chemistry can have a significant effect on formability of steel. Higher carbon and alloy steel tends to get harder as they cool from the rolling/ finishing temperature. Harder steel is stronger (stiffer) and therefore will exhibit more springback between the last fin roll and the weld rolls.

This can result in welding in the peaked condition which may trap (Fig 11) inclusions in the weld. Also, the amount of residuals and gas content of the steel can influence the degree to which the steel work hardens as it is formed. When skelp is tested for yield strength prior to cold forming, it may show entirely normal properties. However, when tested after forming and welding, the yield strength may have increased beyond what the design specification allows (Fig 12). Pipe which has been work hardened to an excessive yield strength can be salvaged by heat treatment but caution should be exercised that in doing so, the yield does not drop too low.



Proper parallel edge registration

Peaked Edge Registration

Fig 11 Parallel and Peaked Edges

Rolling practice may also effect forming due to oxide scale left on the surface of the skelp. Because reversing mills tend to produce a thicker scale than do continuous mills, skelp from a reversing mill presents special problems. As the skelp is formed, scale will break and fall off. The scale can combine with mill coolant and form thick blocks of scale which can adhere to the rolls. The skelp passing under the rolls is left with an impression which appears to be a hot formed pit. However, regular spacing by a distance equal to the circumference of the roll is an indication that it is cold formed. Microstructural examination will also show that the grains below the pit are compressed which would not happen if the pit was made while the skelp was at rolling temperature where the deformed metal grains would recrystalize immediately.

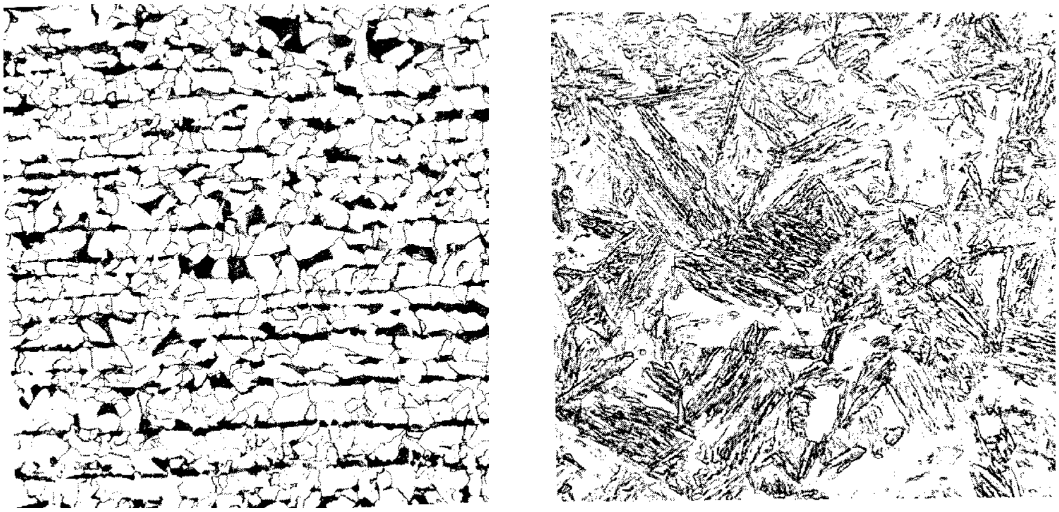
PROPERTY	AS RECEIVED	AS FORMED
TENSILE STRENGTH	72,000 PSI	73,000 PSI
YIELD STRENGTH	55,000 PSI	68,000 PSI
ELONGATION	33%	25%
HARDNESS BHN	137	179

Fig 12 EFFECTS OF COLD FORMING ON THE MECHANICAL PROPERTIES OF STEEL

The crown or thickening of the centerline of the skelp can create forming and welding problems also. If the variation is great enough, one edge can be much thicker than the other. This can cause the thick edge to push the skelp during forming causing a twist as it moves through the mill. The thick edge can also be pinched by the rolls causing one edge to become longer than the other resulting in scalloped or wavy edges.. If the thick edge comes through the mill unchanged, it may create an apparent offset edge after welding and trimming.

WELDING

Higher carbon and alloy chemistries can be difficult to weld because of the segregation of carbon and alloy elements (Fig 13a). The heat of welding causes the metal behind the molten layer to transform to Austenite which, upon rapid cooling , can become very hard (Fig 13b). If seam normalizing is not employed, these hard areas can crack in the sizing stands. High sulfur contents can also promote a brittleness which results in flat test failures.



A:Ferrite/Pearlite base metal Structure
Nital etch at 200x

B: Hardened Martensitic structure near weld
Nital etch at 500x

Fig 13. As Rolled Carbon steel showing banding and Martensitic structure near the weld zone.

Reversing mill skelp, because of the thicker scale, can cause weld defects such as entrapments if cooling water carrying the scale particles is flooded into the vee prior to welding. The thick scale can also cause problems in passing an electric current from the welder contacts to the steel. The scale can build up under the contacts and momentarily push the contact off of the pipe. This results in an arc burn and an instantaneous loss of heat..

Variation in gage caused by poor rolling practice can create fluctuating power demands to which the welder cannot respond rapidly enough. The variations in weld power density causes temperature variations which can mean cold welds or melt off.

Skelp which has had problems in slitting will likely have problems in welding also. Shelving caused by segregation (or dull knives) may not be completely removed by the fin passes. Any lip extending into the vee prior to the squeeze point will act as a short circuit and cause a cold weld (Fig 14).

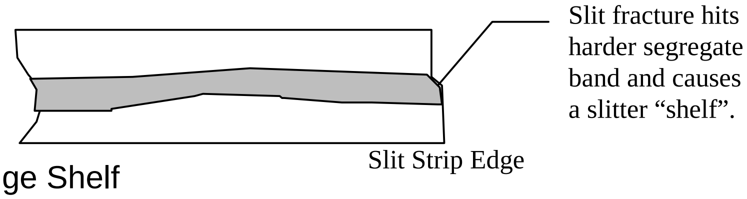


Fig 14. Slit Edge Shelf

The presence of centerline impurities not only causes slitting problems but greatly increases the possibility of hook cracks and stringers adjacent to the weld.

The method of forming can also create defects when applied to certain types of steel. Ingot cast steel with high sulfur and phosphorus will have a larger percentage of stringers and laminations than con-cast clean steel. The use of edge forming and/or cage forming will greatly reduce the amount of work done in the fin passes. This will mean less work on the edges and results in fewer hook cracks and laminations.

POST WELD HEAT TREATING

Post-weld heat treatments include seam normalizing and full body normalizing, annealing and quench and tempering. The most common post-weld heat treatment is seam normalizing. This process heats the weld area back up to about 1800 F and allows it to air cool before water quench prior to sizing. Highly segregated steel from ingot cast mills may actually contain enough carbon and residual alloys in the weld area to harden again after normalizing . This may result in cracking during water quenching and sizing. Pipe produced for transportation of hydrocarbons may exhibit Hydrogen Induced Cracking when gases or liquids containing H_2S are transported through the pipe containing high hardness areas.

Pipe which is full body heat treated will also suffer from segregation when it is Quenched and Tempered. The segregation will result in non-uniform hardnesses that may give rise to galvanic corrosion or poor service performance.

Skelp with gage variations or heavy scale will also have straightness and roundness problems after full body heat treating due to non-uniform cooling. The heavier walls and the insulating effect of heavy scale will cause erratic heat transfer during the quench and the resulting stresses will pull the pipe out of round and/or cause it to bend or hook

CONCLUSION

The process of making pipe and tube from steel skelp has for years been considered a black art. While not disputing the need for skill in pipe making, awareness of the influence of "up-stream" variables on pipe making processes can help us to avoid many of the problems we have discussed . Again, it was beyond the scope of this paper to deal with every variable.

However, if you have specific problems which may be related to mill processing, your Service Center or Steel Mill metallurgists will be ready and willing to assist you. Do not hesitate to solicit their assistance.

SUMMARY

MELTING	CASTING	ROLLING	SEGR'N	SCALE	GAGE	RESIDUAL
EAF	INGOT	CONT	+++	LOW	GOOD	HIGH
EAF	CONT	CONT	+	LOW	GOOD	HIGH
EAF	INGOT	REVERS'G	+++	HIGH`	FAIR	HIGH
EAF	CONT	REVERS'G	+	HIGH	FAIR	HIGH
BOF	INGOT	CONT	++	LOW	GOOD	LOW
BOF	CONT	CONT	+	LOW	GOOD	LOW
BOF	INGOT	REVERS'G	++	HIGH	FAIR	LOW
BOF	CONT	REVERS'G	+	HIGH	FAIR	LOW

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