NICKEL-COPPER MATTE AND SINTER

Processes and Methods of Producing
Rolling Mill Products — October, 1947

The International Nickel Company, Inc.
Huntington Works

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FOREWORD

Since the construction of the Huntington, West Virginia plant in 1922, it has extensively used a nickel-copper matte as a basic raw material in the production of rolling mill products. Starting in 1947 the plant has been shifting over from the use of nickel-copper matte to the use of sinter. Pending consumption of its remaining supply of matte, both sinter and matte are being used.

The following text is descriptive of processes and methods used by the plant in its commercial practice as of October 1947 in the production of rolling mill products from these basic raw materials.

CHAPTER I

CALCINING

Raw Materials

Of the two basic raw materials mentioned above only nickel-copper matte requires calcination or roasting. The matte is in the form of rough irregular slabs two or three inches in thickness and weighing up to 100 pounds. A sample analysis is as follows:

Nickel-Copper Matte

Nickel*	52.77%
Copper	24.78%
Sulphur	21.98%
Iron and impurities	0.47%

Sizing for Roasting

The first step in preparing matte for roasting is the reduction of the slabs to properly sized particles. Accordingly, the slabs of matte are reduced to about 1½" pieces in a jaw-crusher, reduced to about ¼" pieces in a cone crusher and finally ground dry to minus 14 mesh in a ball mill.

Particle size distribution is an important factor, since large particles reduce the rate of sulphur elimination and particles smaller than minus 325 mesh tend to be lost in the furnace gases. A sample screen analysis of a ground matte suitable for roasting

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*In accordance with the practice of the trade, all analyses of nickel content given in this manual include the accompanying cobalt as nickel.

in end-fired, mechanically rabbled furnaces of the Edwards' type, which are used, is as follows:

Screen Size (U.S. Std.)	% On	% Cumulative
12	0.0	0.0
14	0.1	0.1
20	6.4	6.5
30	9.7	16.2
50	21.6	37.8
100	15.2	53.0
200	12.3	65.3
325	12.5	77.8
thru 326	22.2	22.2

Roasting

The rate at which sulphur is eliminated for a given particle size distribution is determined by the relationship between several important factors:

a. furnace atmosphere

b. rate of feed

c. degree of agitation

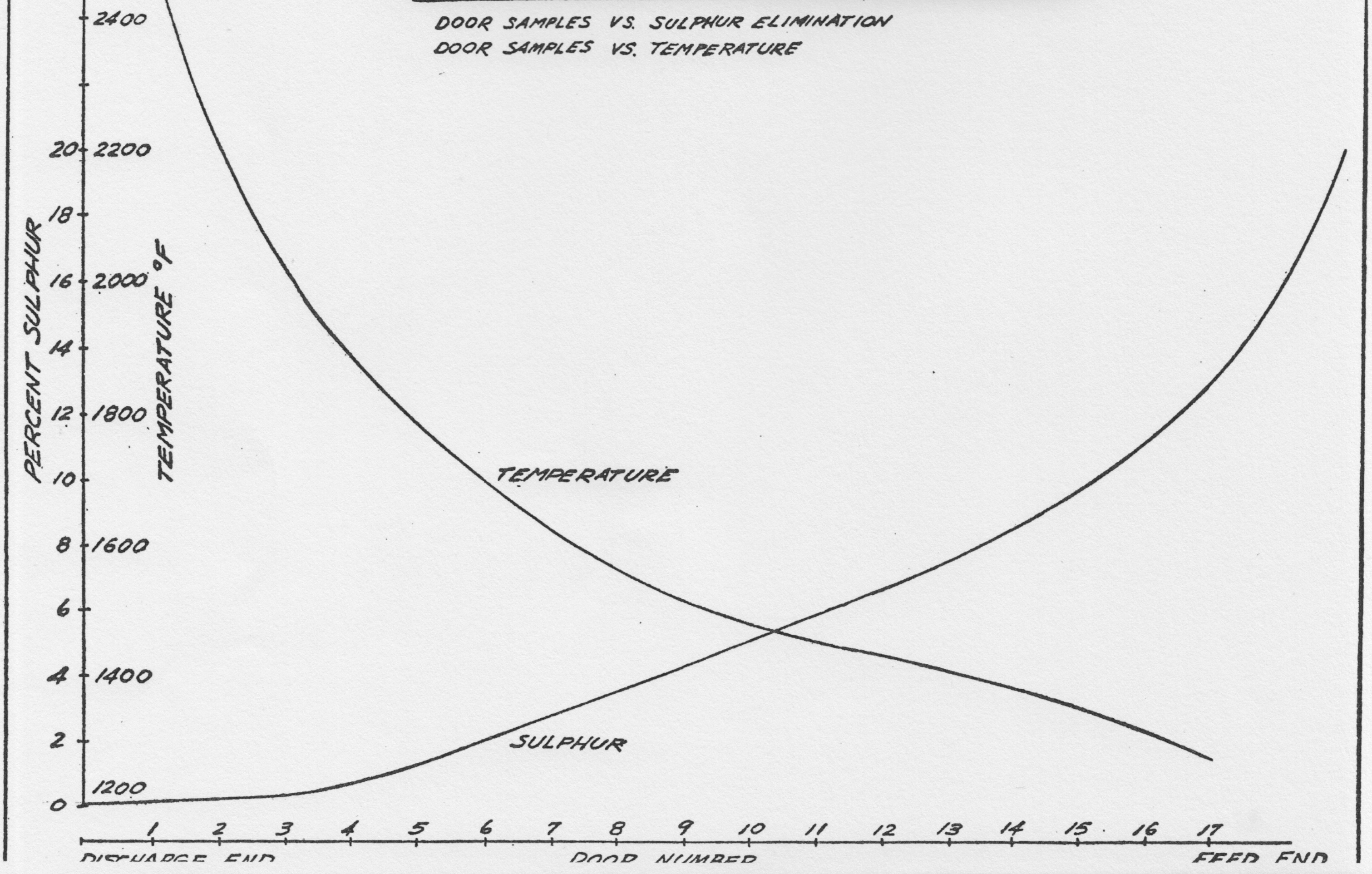
d. furnace temperature conditions

To effect sulphur elimination, the furnace atmosphere is maintained highly oxidizing. Typically the oxygen varies between about 2 to 10%. The fuel used is low sulphur natural gas. The rate of feed and degree of agitation as the matte is advanced through the furnace is such as to provide for an average exposure of 4 hours in the furnace. The temperature gradient in the furnace runs from approximately 1250° F. at the charging end to 2550° F. at the discharge end, since as the sulphur is progressively removed the temperature at which fusion begins is progressively correspondingly higher. Fusion, which would result in increasing the particle size and thereby adversely affect oxidation of the sulphur, is avoided by controlling the rate of feed and speed of travel of the material through the furnace.

The mechanically rabbled furnaces have hearths 12' 11" by 70' 0" and are fed continuously at a rate to maintain a layer of matte approximately four inches in thickness at the charging end. This layer progressively decreases in thickness as the material approaches the discharge end. In this operation the matte is converted from a sulphide into an oxide. The hot oxide is automatically discharged into removable drums located below the floor level where it is blended with charcoal in order to obtain a partial reduction of the oxide to metallics to improve the later melting furnace efficiencies. The capacity of each furnace approximates 20 tons per day of partially reduced nickel-copper oxide containing sulphur of the order of 0.030 per cent. Each furnace consumes about 322,000 cu. ft. of gas per day which at 1150 B.T.U. per cu. ft. is a heat input at the rate of 15,000,000 B.T.U. per hour.

The sulphur removal is graphically illustrated in Table I (curve shown on page 5).

TABLE I
SULPHUR REMOVAL IN ROASTING FURNACE



CHAPTER II

MELTING AND REFINING

The materials entering into melting and refining operations are in the form of oxides; one form called here nickel-copper oxide is the end product of the process dealt with in Chapter I. The other is a sinter (comparable in the combined nickel plus copper and the oxygen content with the nickel plus copper and the oxygen content of the nickel oxide sinter sold to the steel trade, the nickel plus copper being of the general order of 75% by weight).

Open Hearth Furnace Practice

Furnace charges are made up by mixing the oxide or sinter with low sulphur petroleum coke amounting to 15% by weight of the charge. A mechanical mixer provides the thorough and intimate mixing of the oxides and petroleum coke that is required for most effective reduction in the furnace. The desired nickel to copper ratio in the alloy is obtained by adding copper. The major portion of the copper required is added in the open hearth furnace at the time the charge of sinter and petroleum coke are introduced. The final addition of copper is made in the electric furnace after duplexing, as described below, and after the copper content of the melt has been determined by chemical analysis.

The open hearth furnace is constructed of first quality acid fire brick to operate at high temperatures. The fuel is low sulphur natural gas.

The furnace charge is leveled off to expose the largest possible area to the flame and also to minimize deflection of the flame against the furnace roof. The flame is adjusted on the reducing side as an aid in reduction of the oxides to metallics. The atmosphere is regulated to contain 6 to 8% CO while carbon is burning off and approximately 2% CO thereafter.

An effort is made to adjust the reducing agents, so as to have the heat melt down with about 0.25 - 0.40% carbon. This gives a faster and more efficient operation of the furnace and is desirable for subsequent refining operations. An oxidizing melt down is invariably slow and results in gassy metal.

No slag producing materials are added, but slag does result from the fusion of the refractories and from dross in the oxides and petroleum coke. The skimming of this slag is begun when the charge is partially melted and is continued at intervals until the charge is completely melted.

When the charge is completely melted and all slag has been removed, the metal temperature is brought up to about 2700° F. to prepare for tapping. Typical carbon and sulphur analysis at this stage is:

C	0.35%
S	0.090%

The increase in sulphur content is a consequence of the presence of sulphur in petroleum coke. The desired maximum sulphur content of petroleum coke is 1%.

By having sufficient carbon (0.25 - 0.40%), the reducing conditions essential for further desulphurization are assured. While the metal is being tapped into a fire-brick lined ladle, 1% manganese in the form of ferro-manganese is added to the stream. Metallic magnesium equal to 1¼ to 1½ times by weight of the known sulphur content is then plunged into the molten metal contained in the ladle. The magnesium is wired firmly in "U" shaped iron holders which are on the ends of long iron rods or handles. Holders and a portion of the handles are protected by a coating of lime slurry which is carefully dried before any contact with molten metal is made. The magnesium combines with part of the sulphur and floats to the top as magnesium sulphide.

Cryolite is then put on the metal surface to form a slag ¼" to ½" thick which collects the insoluble magnesium sulphide that rises to the top of the metal in the ladle. With the ladle slightly tilted, this slag is then skimmed off. Approximately one-half of the sulphur contained is removed by this operation.

Duplex Process

Duplexing is the double operation of reduction of oxides by melting in the presence of carbon in an acid lined Open Hearth followed by final refining in basic lined direct arc type electric furnaces. The electric furnace is lined with magnesite brick as bottom and side wall to a point above the normal slag line. The bottom is finished and maintained with dolomite. For roof and side walls above the slag line either fire clay or silica brick are used.

Hot metal as prepared in the Open Hearth and treated with manganese and magnesium is transferred to the electric furnace. The metal as received is first skimmed clean of any slag which may have remained from the previous operation. A white slag consisting of about 3 parts by weight of fluorspar and 2 parts of lime is then put on the bath in sufficient quantity to cover the entire surface to a depth of 1 to

2 inches. As soon as this slag is fused, a mixture of finely divided carbon with some lime is scattered over the white slag. The finely divided carbon may be coke breeze or derived from grinding scrap carbon and graphite electrodes. Within a short time the slag is converted into a carbide type, characterized by an acetylene odor when it is immersed in water. The removal of the final sulphur from the bath is then accomplished as follows. A master alloy of calcium-silicon (33% Ca) is added in quantities sufficient to provide calcium in amount equal to 1¼ to 1½ times the sulphur contained. The calcium-silicon is plunged into the molten metal in the same manner as the magnesium was plunged into the ladle. (The sulphur content has been determined by chemical analysis in samples taken after the metal has been transferred to the electric furnace.)

After about 45 minutes the carbide slag which now contains calcium sulphide is skimmed. Extreme care is exercised in the removal of this slag since the subsequent oxidizing treatment would result in the return of sulphur to the bath from residual amounts of slag.

Carbon content is next lowered to the desired level by addition of oxide. The addition of oxide at this point removes any excess calcium and silicon remaining in the molten metal after the desulphurizing operation. A finishing white slag of lime and fluorspar sufficient to cover the surface is then put on the molten bath and samples are sent for the chemical determination of carbon and manganese. Corrections for these elements are made if necessary.

Deoxidation

After the desired carbon and manganese contents have been obtained the metal is deoxidized and degasified by first adding .15% silicon in the form of metallic silicon, followed by .015% phosphorus as copper phosphorus master alloy containing 15% phosphorus. Then .05% metallic magnesium is added followed by .025% titanium as nickel-titanium (45% titanium) and .0025 - .005% zirconium as nickel-zirconium (28% zirconium). In making the additions the metal is maintained at a temperature just over 2700° F. to insure rapid and complete solution of the deoxidizing and degasifying elements. The metal is tapped as soon as possible after the additions are made to prevent excessive loss. This is the standard practice for a nickel-copper alloy in which the nickel to copper ratio is approximately 2.2:1; in the case of substantially higher nickel to copper ratios, the silicon addition is decreased to .10% and the zirconium increased to .010%.

Teeming

At a temperature of 2700° F. the molten metal, after deoxidation and degasification, is tapped into the teeming ladle. The last slag is carried over with the metal into the ladle where, due to its density, it floats on top and so protects the metal from oxidation by the atmosphere and aids in retaining temperature while the metal is being teemed. A period of 1 to 2 minutes is allowed after the ladle is filled to permit the slag to collect on the surface. The metal is then teemed into cast iron molds provided with cast copper bases or "stools" and tile-lined hot tops. An insulating blanket of Armstrong refractory impregnated cork is placed on the ingot top.

The temperature of the cast iron molds at the start of teeming is about 300° F. to prevent undue thermal shock from contact with the molten metal. No dressing is used on mold surfaces since dross in the metal as a consequence of the use of dressing is a greater hazard than is surface roughness of the ingots.

Speed of teeming is controlled by varying the size of the ladle outlet nozzle. The nozzles used range from one having a ½" opening for 10" x 10" x 40" ingots, a 1½" opening for 14" x 14" x 60" ingots, to a practical top limit of a 2" opening for larger ingots. Clay nozzles are used in conjunction with graphite stopper heads.

In starting teeming, metal is poured slowly until an 8" or 10" pool is formed at the bottom of the mold to take the full flow from the nozzle with a minimum of splashing.

Following the teeming operation, the ingots are cooled and stripped from their molds.

A sample analysis of a melt produced into ingots as described is as follows:

C	.15
Mn	1.00
Fe	1.50
S	.005
Si	.15
Cu	30.00
Ni	Balance

<u>Arc Furnace Practice - Cold Charges</u>

Cold charge melts as distinguished from the "duplex" melts are the means by which metal returns from process are converted directly in the arc-type electric furnace into alloy ingots.

Cold charges consist of clean metal returns from process. The heavier material is charged on the bottom of the furnace followed by lighter material on top. General practice is to melt down as rapidly as possible to avoid excessive oxidation and to retain a carbon content of .25 - .35 per cent in the molten bath. Should the carbon content drop below this range, it is increased by addition of petroleum coke or charcoal.

After the charge is melted and skimmed clean of any dross or fused refractories, a lime-fluorspar slag is put on identical to that used for "duplex" melts. From this point the refining closely parallels that of duplex melts. The molten metal is desulphurized by addition of calcium-silicon alloy. It should be noted, however, that during the lowering of carbon, and the removal of excess calcium and silicon with oxide, the greater part of the residual deoxidizers present in the metal returns used are also removed. Therefore it is necessary to carry out complete deoxidation and degasification in the same manner as is used for the duplex melts. The same percentages of deoxidizers are added in the same order. Similarly the melts are teemed and the ingots treated as described under duplexing.

CHAPTER III

CONDITIONING OF INGOTS, BLOOMS AND BILLETS FOR HOT FORGING AND HOT ROLLING

The metal is not free scaling under conditions obtained in furnaces heating for hot rolling and forging. As a consequence, surface defects introduced in casting, forging, or rolling cannot be eliminated by means such as scale breaking, and it is necessary to resort to extensive conditioning or overhauling of the metal surface at various stages of manufacture. For the usual mill production, this involves overhauling the surface of the cast ingot by milling and machine or hand chipping defects not removed by milling; machine chipping blooms forged from the milled and chipped ingot; and machine chipping of billets rolled from the blooms. For other products, details of overhauling are modified as later described for most economical practice consistent with maintenance of quality.

For most products, the metal is cast into 14" x 14" x 60" ingots. For rounds for extrusion into tubing, ingots of 18" x 18" x 40" and 18" x 18" x 68" size are cast. Forgings as such and slab forgings for further processing into sheet or strip products are regularly produced from 14" x 14" x 60", 18" x 18" x 40", 18" x 18" x 60" and larger ingots up to 30" x 30" x 60" size. Slabs for hot rolling into plate are produced from cast ingots 18" x 30" x 48" or 18" x 30" x 60" size.

Milling

Except as later noted all cast ingots are overhauled by milling the side surfaces but not the ingot head until a minimum of 75% of the surface exhibits no porosity, slag inclusions, folds or cracks; the remaining surface imperfections are removed as described later under Chipping. The corners of the ingots are milled to approximately 2" radius. This results in an average milling loss of 5% of the ingot weight.

Ingots in sizes 14" x 14" and 18" x 18" cross sections are milled on special Ingersoll milling machines. These machines mill one side and one corner of two ingots in one operation with up to ¼" stock removal in each pass. The side cutters are of inserted tooth type 24" in diameter containing two rows of 40 teeth each, the inner row being offset ⅛" to effect step cutting. The radius cutters are ten inches in diameter and contain 10 inserted teeth with formed cutting surface. All cutter teeth are of heat treated high speed tool steel. Ingots larger than 18" square and including 30" square cross sections are milled on Cincinnati Hydromatic milling machines. These are conventional type milling machines having inserted tooth head 8" in diameter containing 10 teeth of heat treated high speed tool steel.

Ingots for forged rounds for extruded tubing and for forgings to be subsequently machined, are not milled as the defects present in the ingot skin will be removed in machining operations. Exceptionally for critical machined forgings, the ingots may be milled and chipped before forging and perhaps overhauled at an intermediate stage.

Chipping

Milled ingots are overhauled by hand or machine chipping to remove isolated defects present after milling and the refractory at the junction of the ingot head and body.

Machine chipping is performed on Bonnot - Lenz Billeteers by a rotating head carrying 8 or 10 cutting tools of heat treated high speed tool steel. This machine is designed to permit longitudinal movement of a carriage carrying a cutter along the length of the material being chipped as well as vertical and lateral movement of the cutter head in the carriage to locate the cutter over any defect to be removed. The billeteer machine is limited to ingot sizes of 14" x 14" maximum cross section. Ingots larger than this size are hand chipped after milling. Hand chipping is performed with conventional type air hammers and chisels.

For the usual products, the ingots are forged to 8" x 8", or 4" x 11" blooms; the former for rolling into billets for the various merchant mill products and the latter for rolling into sheet bar. The blooms are inspected for defects which are then removed on the billeteer chipping machines. Forged slabs for direct rolling into strip or sheet are given an overall grind with swing grinding machines as defects introduced by forging cannot otherwise be satisfactorily removed in this product.

The forged and conditioned 8" x 8" blooms are rolled on a 24" breakdown mill into billets for further conversion into the various merchant mill products. The billets produced on the 24" mill are inspected for defects and these are removed by billeteer chipping or by hand chipping. The forged 4" x 11" blooms are rolled into sheet bar on the 24" mill. The sheet bars are inspected for defects and these are removed by hand chipping before rolling into sheet products.

CHAPTER IV

FORGING

Heating

The time of heating preparatory to forging the ingots is just long enough to insure that the desired temperature (preferably 2150° F.) is reached uniformly throughout the material. Excessively long periods at the high temperature are avoided. Heating times generally required for various size ingots are listed below:

14" x 14" x 60" ingots	3½ to 4 hours
18" x 18" x 40" "	6 to 8 hours
26" x 26" x 60" "	10 to 12 hours
30" x 30" x 50" "	12 to 14 hours

The ingots are heated in batch type, side-door furnaces, directly fired through the back wall using low sulphur natural gas. The furnace atmosphere is regulated so as to contain an excess of carbon monoxide and hydrogen with no free oxygen present; in other words, heating is conducted in a reducing atmosphere.

Forging

By forging, cast ingots are converted to forged blooms for later production into hot rolled billets and sheet bars which are in turn hot rolled to strip, bar stock and sheet, and large rounds and shapes outside the limits of hot rolling equipment are produced. For these operations, three reciprocating steam hammers rated at 16,000 lbs., 10,000 lbs., and 3,500 lbs. are used.

The 16,000 lb. steam hammer, which has a die face 9" x 31", is used principally for forging the standard size ingots (14" x 14" x 60") into blooms 8" x 8" x approx. 1,300 lbs. and blooms 4" x 11" x approx. 1,300 lbs., for later conversion to strip, bar stock and sheet; larger ingots up to 30" x 30" x 58" (16,500 lbs.) are forged into miscellaneous sections including slabs. In addition, this hammer is used to produce forged rounds and squares from 4½" to 24".

The 10,000 lb. steam hammer, which has a die face of 9" x 28", is used to forge ingots within the size range 10" x 10" to 14" x 14" and to produce miscellaneous forged sections which are too large for the 3,500 lb. hammer and not large enough to produce economically on the 16,000 lb. hammer.

The 3,500 lb. steam hammer has a die face 8¾" x 18¼". This hammer is used principally for forging billets, slabs, rounds and rings and smooth forged squares, hexagons and rectangles which are not large enough to economically forge on the 10,000 and 16,000 lb. hammers.

The die blocks for these hammers are made of a composition that is resistant to abrasion, warping and fire cracking. A sample chemical analysis of the steel is as follows:

C	Mn	Si
.50-.60	.45-.65	.15-.25

Ni	Cr	Mo
1.40-1.75	.70-.80	.70-.80

The 16,000 lb. and 10,000 lb. hammers are served by electrically operated manipulators. Likewise the ingot heating furnaces are served by an electrically operated machine for charging the cold ingots and withdrawing the heated ingots. The transfer of the heated ingots from the latter to the former is accomplished through the use of turn tables suitably located in the separate tracks on which these machines travel. The 3,500 lb. hammer and its complementary heating furnaces are manually served.

Ingots, after heating to approximately 2150° F. as previously discussed, are first subjected to relatively light forging reductions on all four sides preliminary to the heavy roughing down operations. This precaution is necessary only when the metal to be forged is in the "as cast" condition. Heavy reductions are confined to the period during which the metal is within the temperature range 2150°-1700° F. When it is necessary to forge below 1700° F., only light reductions are made. The overall reduction in cross-sectional area following any heating operation is at least 50% to accomplish grain refinement.

The forging limitations on slabs are as follows:

Thickness, in.	Max. width, in.
3	14
4 to 5	24
6 to 18	30

The forging limitations on rounds are as follows:

Diameter, after Rough Machining, in.	Max. length, ft.
4½ to 5	22
5¼ to 6	25
6¼ to 7	30
7¼ to 8	35
8¼ to 9	43
9¼ to 10	40
10¼ to 24	12,000 lb. rod

The sectional limitations for smooth forged hexagons are from 2¼" to 8"; for squares from 2⅜" to 6"; for rectangles 1½" to 2" x 8" or less and 2" to 6" x 10" or less.

The mechanical properties of finished forgings, as distinguished from blooms, billets and slabs, are dependent upon the size of the finished piece and the finishing temperature used. High tensile properties are obtained by finish forging near the lower end of the hot working temperature range (1000 - 1400° F.).

For certain applications forgings are subjected to low temperature annealing within the range 1000 - 1300° F. This treatment moderately decreases hardness, yield strength and ultimate breaking strength, at the same time moderately increasing the elongation and reduction of area values as illustrated in Table II below. It also effectively minimizes warpage after machining.

TABLE II

THE EFFECT OF TEMPER ANNEALING ON PROPERTIES OF A 6" DIA. FORGED ROUND

Temp. ° F.	Time at Temp.	Yield Strength (.2% offset) psi	Tensile Strength psi	Elong. in 2" %	Red. of Area %	Rockwel "B" Hardnes
as forged	–	61,000	91,500	36.5	71.7	89
1200	6 hrs.	50,500	88,500	42.0	72.7	83
1290	2 hrs.	43,500	87,000	44.0	72.8	79

CHAPTER V

MERCHANT MILL ROLLING

Heating

Heating the metal preparatory to hot rolling is carried out in batch-type, side-door furnaces direct-fired through the back wall using low pressure premix type burners. The fuel is low sulphur natural gas and the furnace atmospheres are maintained reducing, that is to say combustion is controlled to give approximately 5% hydrogen plus carbon monoxide with no free oxygen present. The temperature to which the metal is heated will vary from a high of approximately 2150° F. for large sections such as 8" x 8" and 4" x 11" blooms to a low of about 1900° F. for small sections such as 2" x 2" billets. No reheating is normally required during the rolling of standard shapes.

Rolling Billets and Sheet Bars

Forged 8" x 8" and 4" x 11" blooms, after overhauling by mechanical chipping, are hot rolled to billets and sheet bars on a breakdown mill. This mill consists of a stand of 3-high 24" diameter roughing rolls with tilting tables on front and back sides and a stand of 2-high finishing rolls. The mill is driven by a 1200 horsepower motor with a speed of 353 rpm, a gear reduction of 4.5 to 1 giving a roll speed of 77½ rpm.

The passes, reductions per pass and sizes obtained in rolling an 8" x 8" bloom into billets are shown in Table III.

TABLE III

BREAKDOWN MILL
Passes, Reductions per Pass, and Sizes of Billets Produced

Pass	Roll Opening Inches	Reduction Per Pass - %	Billets Produced, Inches
1	8 x 7	12.3	
2	8 x 6	14.3	
3	6 x 7	12.5	
4	6 x 6	14.3	6 x 6
5	6 x 5	16.6	5 x 6
6	6 x 4	20.0	4 x 6
7	4 x 5	17.0	4 x 5
8	4 x 4	20.0	4 x 4
9	4 x 3½	12.5	
10	4 x 3	14.3	3 x 4
11	3 x 3	25.0	3 x 3
12	3 x 2½	17.0	
13	2½ x 2½	17.0	2½ x 2½

In hot rolling 4" x 11" blooms to sheet bar, reductions of 20 - 25 per cent per pass are applied. The blooms are not edge rolled and consequently the finished width of the sheet bars varies slightly but is approximately 11¾". The thickness of the finished sheet bars is from .280" to 2¾", depending upon the gauge and length of the sheets to be produced subsequently.

TABLE IV

BREAKDOWN MILL

Passes, Reduction per Pass for Sheet Bar

Pass	Roll Opening Inches*	Reduction per Pass - %*
1	2-3/4 x 11-3/4	31
2	2-1/16 x 11-3/4	25
3	1-9/16 x 11-7/8	25
4	1-1/8 x 11-7/8	28
5	13/16 x 12	28
6	5/8 x 12	23½
7	Varied to suit foot-weight (.280 to 2¾)	

*Roll openings and corresponding reductions per pass shown are nominal and may be varied by moving top or bottom rolls up or down according to the various foot-weights produced. Width of opening remains constant.

Rolling Rods, Bars, Flat Stock, etc.

In a typical operation billets produced on a breakdown mill are overhauled and rerolled into rounds, shapes, flats or strip on one of a series of mills depending upon the sizes to be produced. For example:

(a) The 20" mill consists of four stands of 3-high 20" diameter rolls and a finishing stand of 2-high 20" diameter rolls. It is driven by a 1000-horsepower motor with a speed of 400 rpm, a gear reduction of 7.5 to 1, giving a roll speed of 53.3 rpm.

Rounds from 4½" to 2" diameter in steps of 1/16" are produced on this mill by the "hand round" method. In making these rounds, only two 3-high stands and the 2-high finishing stand are used. The finishing stand has rolls with a series of circular grooves ranging from 4½" to 2" diameter. As an example, Table V shows the development of a 3" diameter round starting with a 5" x 6" billet.

T A B L E V

20" Mill - Development of a 3" Dia. Round

Pass	Stand	Size of Roll Opening	Reduction %
1	3-high	5" x 5"	16.6
2	3-high	5⅛" x 3⅞" (Corners rounded)	24.0
3	2-high	4" dia.	21.0
4, 5	2-high	3¾" dia.	12.0
6, 7	2-high	3½" dia.	12.0
8, 9	2-high	3¼" dia.	14.0
10, 11, 12 and 13	2-high	3" dia.	14.0

The 20" Mill is also used to produce strip in widths from 18½" to 3-13/16" and in thicknesses from .125" to .250". In rolling strip, the first 3-high stand consists of one "flat" and one edging pass. In the second stand there is a set of step rolls. The remaining stands have cylindrical ("flat") rolls. Reductions per pass of 15-30 per cent are used in making strip.

Flats 10" to 4" wide and ¼" to 1½" thick are also produced on this mill. Flats are rolled in the same manner as strip, except that two edging passes are usually applied.

(b) The 14" Mill has four stands of 3-high 14" diameter rolls and one stand of 2-high 14" diameter rolls. It is driven by an 800 horsepower motor through a reduction gear to deliver a roll speed of 99 rpm. This mill requires billets 3" x 4" or smaller and produces rounds 2" to 1-1/16" diameter; squares and hexagons 2⅛" to 1-1/16"; flats 1" x 4" to ½" x 1½" and strip from 3⅞" to 2" wide x ¼" to ⅛" thick.

In Table VI is given the development of a 1½" diameter round from a 3" x 3" billet.

The rolling of strip and flats on the 14" Mill is similar to the 20" Mill in setup and reductions.

T A B L E VI

14" Mill - Development of a 1½" Dia. Round

Pass	Size of Roll Opening	Shape of Opening	Reduction per Pass - %
1	2¼" x 2-29/32" (Diagonal)	Diamond	27.3
2	1⅝" x 2-9/64" (Diagonal)	Diamond	12.8
3	1⅜" x 2¼"	Rectangle	10.4
4	2"	Modified Oval	4.5
5	1-13/32" x 2⅛"	Oval	26.4
6	1½" dia.	Round	18.4

(c) The 10" Mill is similar to the 14" and 20" Mills in that it has four stands of 3-high rolls and a finishing stand of 2-high rolls. The mill is driven by a variable speed 500 horsepower motor through a reduction gear to deliver roll speeds from 130 - 180 rpm. Billets 2" x 2" x 55 lb. or smaller are fed to the mill to produce rounds 1¼" to ⅜" diameter, flats from 7/16" x 1¼" to ⅝" x 1⅝" and .125" strip from ½" to 2-5/16" wide. This mill produces other sections as squares, hexagons, octagons, half rounds, half ovals and angles.

Rolling Wire Rod

The 9" Mill used for the production of wire rod and narrow strip consists of 12 stands of rolls set up in three sections - (1) roughing, (2) intermediate and (3) finishing. The roughing section is made up of 3 stands of 14" diameter rolls; the first stand is 3-high, the second and third stands are 2-high. This roughing section is driven by a 1000 horsepower motor delivering a roll speed of 158 rpm and reduces a 2½" x 2½" billet x 115 lb. to an oval approximately 5/16" minor axis x 1¼" major axis in 9 passes. This breakdown oval is fed to the intermediate section by a runway. The intermediate section is made up of 5 stands of 2-high 9" diameter rolls. In the intermediate section the oval is converted to a 5/16" square in 5 passes of alternate square and oval shapes. Rods 5/16", 3/8" and 7/16" diameter, as well as strip .125" x 3/4" to 1-9/16" wide, are finished from this second section of stands. For making smaller sized rounds, 1/4 - 9/32" dia., the 5/16" square from the second section is automatically looped to the finishing section of 4 stands of 2-high 9" diameter rolls. This last section finishes the wire rod in four passes by going to an oval, square, oval and finally to a round. The intermediate and finishing sections are driven by a 500 horsepower motor with the intermediate section of rolls travelling at 325 - 400 rpm and the finishing section of rolls turning at 440 rpm.

In making wire rod, the reductions per pass range from 15 to 45 per cent.

CHAPTER VI

EXTRUSION

The extrusion process is used to convert solid rounds into tubular products. The sequence of operation is as follows:

1. The material to be extruded is supplied in the form of long hot rolled or forged rounds.

2. The rods are turned to remove surface imperfections and to produce uniform diameter.

3. The surface of the turned rods is conditioned further by chipping with pneumatic chisels to remove any imperfections persisting after turning.

4. The turned rods are sawed into short lengths suitable for use in the extrusion press.

5. The short lengths ("billets") are heated to 2060° F. - 2175° F. in a reducing atmosphere.

6. The billets are extruded to form tubes.

7. The tubes are sawed to the desired length.

Rod Turning

The machine employed for turning the rounds is commonly termed a "Bar Peeler", and consists of a rotating cutting head through which the rounds are fed by an hydraulic mechanism. The cutter head is driven by a 200 hp dc motor with a speed range of 360 to 1400 rpm. The motor drives through a two speed gear box, giving a cutter head speed range of 7 to 80 rpm. The feeding mechanism consists of an input and output carriage on the respective sides of the cutter head. These carriages are hydraulically driven and equipped with hydraulic clamping devices. The maximum feeding rate of these carriages is 15 ft. per min. The rotating cutter head is equipped with 4 to 7 cutters depending on the diameter rod being turned. An 18% W - 4% Cr - 1% Va general purpose high speed steel, hardened to 62-64 Rc, is used for the cutters. The size of the cutter is 2" x 2" x 6". A cooling and lubricating solution consisting of 50% of soluble oil in water flows over the work during turning.

The hot rolled or forged rounds, after having one end sawed square to permit even cutting entrance and to minimize tool breakage, are turned to the desired diameter in one pass through the machine. The machined diameter is determined by the size of the extrusion container in which they will be used.

The operating data for the bar peeler are tabulated in Table VII.

TABLE VII

Operating Data for Bar Peeler

Size before turning	Size after turning	No. cutters in Rotating head	Feed in. per min.	Speed ft. per min.
7-1/16" dia.*	6.900"	4	7.5	55
9-5/8" dia.	8.750"	5	5.0	45
11-5/8" dia.	10.700"	6	3.2	40
12-3/4" dia.	11.87"	7	3.2	36.5

*The 7-1/16" dia. round is hot rolled, the larger sizes are forged.

Chipping

In the event that harmful surface defects exist after turning to size, such defects are removed by hand operated pneumatic chisels of conventional design operating on an air pressure of 90 psi. The chisel is a 2.75 W - 1.25 Cr - 0.50 C steel hardened to 59 Rc.

Sawing

After turning and chipping, the rods are sawed into short lengths suitable for use in the extrusion press, the length of the billet being determined by the weight of the tube to be produced therefrom.

The saws are of conventional design for cutting heavy metal sections. They are 38" in diameter and are tooled with high speed steel. The saws are driven by a fifteen hp motor through a variable speed gear box, the feed being maintained by a low pressure type hydraulic unit using 240# pressure. A cooling and lubricating solution consisting of 50% of soluble oil in water flows over the work during sawing. The speed of the saw is 43 ft. per min., and the feed is 0.50" to 1.2" per min.

Billet Heating

The billets are heated in a furnace which is 27 ft. diameter and has a 5 ft. wide rotating hearth. Forty-three hearth plates are set equi-distant around the hearth to support the billets. The wall of the furnace is supported by means of water cooled boxes and a water seal is used between the moving hearth and the stationary wall of the furnace. Pneumatic tongs are used for charging and discharging the billets.

The burners are arranged in three zones, the temperature of each zone being independently controlled by means of a radiation type pyrometer. The fuel used is low sulphur natural gas. The furnace atmosphere is maintained reducing by controlling the air-gas ratio on the burners and by flue dampers which enable a positive gas pressure within the furnace and prevent infiltration of uncontrolled air. The furnace atmosphere is maintained at 3% to 4% CO equivalent to 6% to 8% total combustibles with no free oxygen present.

Table VIII indicates the usual heating time and temperature for various size billets.

T A B L E VIII

Billet Heating Times and Temperatures

Billet Dia.	Time in Furnace	Billet Temp. Attained
6.900"	1½ hrs.	2060° F.
8.75"	2 "	2150° F.
10.7"	3 "	2150-2175° F.
11.87"	3 "	2175° F.

Extrusion

The production of tubing is effected by piercing and extruding solid billets, in the press, as parts of a single operation. The piercing mandrel is actuated by a separate hydraulic system, and moves coaxially with but independently of, the main extrusion ram within which it is partially withdrawn initially to allow the billet to be fed into the container. The piercer is driven through the billet, ejecting a small plug of metal. The main ram and piercer, the latter serving as a mandrel, advance together to extrude the tube. After the extrusion, the die is unlocked from its position at the outlet end of the container and the unextruded portion of the billet ("discard") is forced from the container. The die and die holder assembly, bearing the tube and discard, is shifted axially to a hot saw where the discard is cut from the tube to facilitate removal of the tube from the die. The tube, after quenching in a solution of 2% alcohol in water, is cold sawed to the desired length and to square the ends.

The extrusion press is of the horizontal, four column type, developing 4,000 tons total force at 4,250 psi hydraulic pressure. The piercing cylinder develops 1,500 tons, working independently of the main ram which develops 2,500 tons.

The pressure system for activating the press is composed of two three-throw horizontal pumps driven at 120 rpm, through reduction gear sets connected to 720 rpm, 400 hp motors. The pumps each have a capacity of 95 U.S. gals. per min. at 4,250 psi.

The press has four sizes of containers permitting the use of four billet sizes as indicated in Table IX.

TABLE IX

Container and Billet Sizes

Container Inside Diameter	Billet Diameter
7-3/32"	6.900"
9"	8.750"
11"	10.700"
12-1/4"	11.87"

The tools which contact the metal during extrusion are of conventional design except as noted below. The tools are as follows:

1. A pressing disc bored to pass the mandrel is slipped over the mandrel and serves to protect the main ram from wear. The face of the pressing disc which contacts the billet is convex, being tapered at a 25° angle.
2. The solid concave die has a 25° taper on the face, parallel to that on the pressing disc, a ¾" entrance radius which leads to a ¾" long land with a 4° relief behind the land.
3. The mandrels have a 0.040" taper in their length, their leading end being shaped to provide a friction fit for the piercer point.
4. The hemispherical piercer point is placed on the leading end of the mandrel to protect the end of the mandrel from excessive wear during piercing. The piercing point is ⅛ to ¼" larger in diameter than the mandrel, enabling the mandrel lubrication to remain intact during the piercing operation.
5. The container liners are of conventional design.

The nominal composition and hardness of the commonly used tools are tabulated in Table X.

TABLE X

Composition and Hardness of Extrusion Tools

	Analysis					Hardness
	C %	Cr %	Mo %	W %	Fe %	Rc
Container Liner	0.35	5.0	2.25	1.25	bal.	35
Mandrel	0.28	3.25	–	9.0	"	46
Piercer Point	0.28	3.25	–	9.0	"	46
Pressing Disc	0.28	3.25	–	9.0	"	46
Die (1)	0.28	3.25	–	9.0	"	46
or (2)	0.35	4.75	1.5	1.2	"	46

The liners are uniformly preheated to 500° F. and all other tools to 700° F. prior to service to avoid cracking from thermal shock during the first few extrusions.

All the tools are thoroughly lubricated before each extrusion by swabbing with a suspension of graphite in tallow or heavy petroleum oil supplemented by another lubricant composed of an asphalt tar impregnated with flake mica.

The data for typical press operations are tabulated in Table XI.

T A B L E XI - Operating Data for Typical Tube Sizes

Tube Size	Container Size	Billet Size	Extrusion Ratio*	Billet Temp.	Unit Force** tons per sq. in.
2½" OD x 5/16" Wall x 10'6" long	7-3/32"	6.9" dia. x 10" long	16.7	2060° F.	42.7
3¼" OD x ⅜" Wall x 10'6" long	7-3/32"	6.9" dia. x 14" long	10.0	2060° F.	42.5
3¼" OD x ½" Wall x 8' long	7-3/32"	6.9" dia. x 14" long	8.0	2060° F.	33.0
2½" OD x 5/16" Wall x 22' long	9"	8.75" dia. x 10" long	28.8	2150° F.	46.0
3¼" OD x ⅜" Wall x 20' long	9"	8.75" dia. x 14" long	20.0	2150° F.	44.2
4" OD x ⅜" Wall x 18' long	9"	8.75" dia. x 18" long	12.9	2150° F.	37.2
5-9/16" OD x ¼" Wall x 24'6" long	11"	10.7" dia. x 16" long	17.9	2175° F.	37.5
5-9/16" OD x ½" Wall x 14'3" long	11"	10.7" dia. 18" long	9.9	2175° F.	37.6
6.625" OD x .280" Wall x 18' long	11"	10.7" dia. 18" long	11.8	2175° F.	38.0
8" OD x ⅜" Wall x 15'6" long	12"	11.87" dia. x 18" long	8.5	2175° F.	39.0
9¼" OD x 7/16" Wall x 11' long	12"	11.87" dia. x 17" long	5.2	2175° F.	47.8

* = Ratio of pierced billet cross sectional area to cross sectional area of extruded tube.

** = Tons per sq. in. of pierced billet cross sectional area.

CHAPTER VII

PRODUCTION OF SHEET

Hot Rolling

The starting material for the production of sheet is sheet bar which is described in Chapter V on Merchant Mill Rolling. The size of hot rolled sheet bar ranges from 0.280" to 2¾" thick by approximately 11¾" wide, the length of the bar being the desired width of the sheet to be hot rolled. The cross-sectional area of the sheet bar is proportional to the thickness and length of the desired hot rolled sheet. For an extremely thick, long sheet an extra thick, forged sheet bar is used to furnish the required cross-sectional area.

The hot rolled sheet bar is inspected and hand chipped to remove any defects which might affect the quality of the finished sheet. The defects in the forged sheet bar are removed by grinding before being transferred to the sheet mill.

The heating is done in open, batch-type, gas-fired furnaces, which are operated at a positive pressure and a reducing atmosphere. The atmosphere contains less excess combustible gas than is the case in the heating furnaces for forging and merchant mill rolling. This is done to prevent excessive sticking of the sheets when they are rolled in packs.

The approximate atmospheres and temperatures used on the heating furnaces are:

Furnace	% $CO+H_2$	Operating Temp. °F.
Pair	4	2100
Reheat	4	2180
Sheet	1	2000-2080

The hot mills have capacity for rolling sheets from .018" to .270" thick, 20" to 60" wide, and a maximum length of 144" on light gauges and 177" on some heavier gauges.

The hot mills are driven by a single 1200 hp motor with two 10-ton flywheels. The motor speed is 353 rpm, which is geared down to operate the rolls at 25.5 rpm. A friction drag at the end of the roll train is used to reduce backlash.

Each mill consists of two stands of two-high 31" diameter rolls, a roughing stand and a finishing stand.

The roughing rolls are nickel chromium cast iron, and are 44" and 66" long. The top and bottom roughing rolls are both driven. The top roll is counterbalanced by a weight hanging in the pit to give sensitivity to the motor driven screwdown. The 44" rolls are ground with .005" crown, and the 66" rolls are ground with .020" crown. The roughing rolls are cooled intermittently with water and are kept in condition by an automatic polishing device which passes an 80 grit stone back and forth over the surface.

The finishing rolls are chill cast nickel molybdenum iron. Various length rolls are used depending upon the width of sheet to be rolled. It is desirable to use rolls only a little wider than the sheets being rolled. The top roll is friction driven by the bottom roll. The screwdown is hand operated. Rolls from 36" to 44", across the face, are ground with .020" concavity in the top roll and .015" in the bottom roll; 48" with .015" in the top and .010" in the bottom; 56" with .005" in both top and bottom; and 66" are ground flat. The rolls are warmed in electrical resistance heating jackets to 400° F. before use. During operations, the roll temperature is maintained at approximately 650° F., using live steam. The roll surfaces are kept in proper condition while in the mill by means of an automatic polishing machine carrying an 80 grit stone.

The first step in hot rolling sheets after the sheet bars reach temperature in the pair furnace is to rough them down to ¼" thick on the roughing stand. The bars are cross rolled, so that the length of the bar becomes the width of the sheet. Rolling is done by the hand method; each sheet is handled individually by hand tongs and is returned over the top roll for successive passes until the required reduction is obtained or until reheating is necessary. The reduction per pass usually runs 20-30%. During the roughing down operations, the temperature drops to the extent that reheating is necessary before further rolling.

When the ¼" bars reach temperature in the reheat furnace, they are removed and given a few single passes to approximately 0.140" thick on the finishing mill. The maximum reduction per pass is 25%, decreasing as the temperature decreases. These intermediate sheets are then placed in the sheet furnace for reheating. Sheets over .098" are finished singly; over .050" to .098", in pairs, .040" to .050", in three sheets per pack; over .023" to .039", in pairs doubled; .023" and under, in packs of three doubled.

The hot rolled sheets are next trimmed roughly to size, leaving approximately 1½" extra width and 3" extra length.

Annealing

The hot rolled sheets are annealed in order to soften them for subsequent cold rolling and to reduce the oxide film to the metallic state for easier pickling. This is done in a continuous annealing furnace. The hearth consists of discs mounted on revolving steel shafts, spaced on 12" centers. All the shafts in the hot zone and some of the shafts in the cooling zone are water cooled. The hot zone is 60 feet long, and the cooling zone is 110 feet long.

Heating is accomplished with direct fired natural gas through burners a few inches above the conveyor level. The air-gas ratio is regulated to yield an atmosphere containing approximately 9% $CO+H_2$. Heat is removed from the cooling chamber by trays of running water on the roof.

The furnace accommodates sheets up to 60 inches wide. The speed of the conveyor can be regulated from 8 to 26½ feet per minute. Furnace temperature and annealing speeds are discussed later in this chapter under the heading Annealing Cold Rolled Sheets.

Individual hot rolled sheets are loaded onto the conveyor manually from a stack of sheets. No carrier sheets are used; the sheets which are being annealed are carried directly on the rotating discs. As the annealed sheets emerge from the furnace, they are removed from the conveyor by hand and stacked, ready to be transferred to the pickle house.

Pickling

The pickling equipment consists of four steam operated Mesta machines with three tanks at each machine, for acid, rinse water, and neutralizer. Each machine has four arms to support four pickling crates so that one is always available for loading during the action of the solutions. Two of the machines have lifting capacities of 10,000 pounds; and the other two, 16,000 pounds. The tanks are built of concrete, with a lining of dense vitreous acid proof brick (60% silica and 40% alumina) which is bonded with an acid proof cement made of silica flour in sodium silicate solution. The reciprocating vertical motion of the machine produces vertical and also some lateral motion of the sheets which stand on edge in the crates and are separated by spacers. The maximum width of sheet with standard loading is 55". The maximum length varies with the different tanks and ranges from 157" to 198".

The acid pickling solution for each tank is made up as follows:

Sodium Nitrate	1,700 lbs.
Sulphuric Acid, 60° Bé	5,000 lbs.
"Spent" Pickling Solution	1,000 gal.

Add water to make 4,300 gal. final solution.

When no spent pickling solution is available, an equivalent volume of water is used instead, and 725 lbs. of blue vitriol ($Cu\ SO_4 \cdot 5\ H_2O$) are added in order to provide copper ions, which otherwise would have been available from the spent solution. The presence of a minimum of 5 g.p.l. of copper facilitates pickling.

The pickling solution is operated at a temperature of 180° to 190° F. and the average pickling time cycle approximates 2 hours. Heat is supplied by live steam introduced through a carbon pipe.

The rinse solution is plain water contained in the second tank of the circuit. The neutralizing solution is in the third tank and consists of approximately 8½% by volume of 26° Bé aqua ammonia. The neutralizing reaction is accelerated by air agitation in addition to the motion of the machine. Since all four arms of the machine have to move simultaneously, the time in the rinse and ammonia is the same as in the acid.

The acid solution is maintained at a minimum of 7% acid until the nickel and copper salts cause the solution to reach 40° Bé. During this time, when acid is added, sodium nitrate is added proportionately. When the solution reaches 40° Bé, no further additions of acid and sodium nitrate are made but pickling is continued until the concentration of free acid does not exceed 4%. The solution is then considered as "spent" and a new solution is made up as indicated above.

After the sheets have been pickled, rinsed and neutralized, they are scrubbed on both sides in a machine utilizing jets of water and steam together with rotating palmetto scrubbing brushes. The sheets are dried in passing through a hot air drier located at the exit end of the scrubber.

Cold Rolling

The hot rolled sheets after annealing and pickling are delivered to the cold mill for further processing.

Standard cold rolled sheets are cold rolled up to 20% reduction. They may be annealed after cold rolling to provide soft properties or finished as temper cold rolled; the latter type sheet may be furnished also with a ground finish. Tempered sheets receive 3 to 5% cold reduction and may be supplied with as-rolled surface or a ground surface.

The eight cold rolling mills have the bottom roll flat and the top roll crowned. The ends are relieved .002" for a distance of 2 inches to allow for expansion due to heating of the roll necks. The cold mills are equipped with "billey" rolls which are used to press the light gauge sheets against the top working roll for the prevention of pinches and whips. The bottom roll can be heated by means of soft gas flames at selected spots to control flatness in the sheets. The screwdowns are hand operated except on one cluster mill and the four high mill; on the latter two mills, the screwdowns are motor-driven.

One 31" x 66" two high mill is used for cold rolling all sheets over 48" wide which finish over .093" thick. The rolls are cast iron. The top roll is ground with .020" crown using a 60 grit wheel. The top roll is friction driven by the bottom roll which in turn is driven through the hot mill train.

One 26" x 66" two high mill is used for light reductions on wide sheet. The rolls are chill cast nickel chromium iron. The top roll is ground with .015" crown using an 80 grit wheel. The rolls are dressed in the stands when necessary with an 80 grit stone and 1½ grit cloth. Both rolls are driven. This mill is equipped with a mechanical conveyor to return the sheet over the top of the roll for successive passes.

One 26" x 56" two high mill is used for cold rolling sheets over .078" finished thickness and up to 48" wide. This mill is also used for temper rolling sheets up to 48" wide in finished thicknesses .021" and above. The rolls are forged and hardened steel. The top roll is ground with .010" crown using an 80 grit wheel. The rolls are dressed with 80 grit stone and 1½ grit cloth. Both rolls are driven. This mill is also equipped with a mechanical returning table.

One 26" x 56" two high mill is used for the same purpose as the mill mentioned in the preceding paragraph. This mill is like the preceding one except it has a crown of .004" on the top roll.

One 26" x 56" two high mill is used for skin passing sheets up to .078" and to 48" wide. This mill is sometimes used for temper rolling thin sheets. The rolls are forged and hardened steel . The top roll is ground with .004" crown using a 120 grit wheel. The rolls are dressed with a 180 grit stone and 220 or 360 grit paper. Both rolls are driven. Sheets rolled on this mill receive only one pass and, therefore, there is no table for returning the sheets over the rolls.

Two cluster type mills with 14" diameter x 42" working rolls, each roll being backed up by two 24" x 42" rolls, are used for standard cold rolled sheet up to .078" in finished thickness and in widths up to 36". All the rolls are forged and hardened steel. The top working roll is ground with .004" crown using an 80 grit wheel. The working rolls are dressed with number one emery cloth for rolling finished thicknesses heavier than about .043", whereas they are dressed with number ½ to double nought emery cloth for finished thicknesses lighter than .043". Both working rolls are driven, with the back-up rolls idling against them.

A four high mill with 13" x 60" working rolls and 26" x 60" back-up rolls is used for 20% cold reduction of sheets up to .078" finished thickness in widths up to 56". All the rolls are made of forged and hardened steel. The top working roll is ground with .009" crown using an 80 grit wheel. The rolls are dressed the same as the cluster mills. Both working rolls are driven.

The four 26" mills described above are in a single train driven by a 300 hp motor, turning at 293 rpm. A gear reduces the speed to 25.5 rpm on the rolls.

Each cluster mill is driven by a 750 hp variable speed motor with a range of 300 to 600 rpm. The gear reduction results in a roll speed of 24 to 48 rpm.

The four high mill is driven by a 250 hp variable speed motor with a range of 700 to 1400 rpm. The gear reduction results in a roll speed of 20 to 40 rpm.

In the cold rolling of sheets, kerosene is used on the rolls for all passes with the exception of the first two passes on the cluster mills and the four high mill; in the latter instances, dry rolling assists in closing the surface pores of the sheets. Sheets which are rolled on the mills with mechanical returning devices are rolled individually to final thickness; whereas on the other mills each sheet in a lift is given one pass and then the entire lift is moved around the mill for the second pass on each sheet, and so on until the sheets reach the desired final thickness. The reduction per pass varies according to the mill and the dimensions and physical properties of the sheet. For any given sheet, the first pass receives the greatest reduction. As the sheet becomes harder, the reduction per pass decreases, even though the rolls are continually closed with the screwdown. The cluster mills and the four high mill, for example, usually give about 6% reduction in the thickness on the first pass.

The standard limits for cold rolling sheet are as follows: .018" to .250" gauge, 20" to 60" wide, and up to 144" long. Not every width and length can be furnished in every thickness. For example, extremely thin or extremely thick sheets cannot be rolled to 144" long.

Annealing Cold Rolled Sheets

The cold rolled sheets are annealed in the same continuous bright annealing furnace that is used for the annealing of hot rolled sheets. The following data are illustrative of the time-temperature cycles used:-

Thickness of Sheet. Inches	Temperature of Heating Zone. °F.	Time of Exposure in Heating Zone. Minutes
Up to .046	1800	2.3
.047 - .062	1800	2.4
.063 - .078	1800	2.9
.079 - .093	1800	3.7
.094 - .109	1800	4.4
.110 - .125	1800	5.7
.126 - .136	1800	6.6
.137 - .140	1800	7.3
Over .140	1800	7.4

Carrier sheets are used to prevent scratches and dents from the hearth discs. Spacer bars are also used on sheets up to .043" gauge to promote circulation of the hot gases under the sheet and to prevent sticking to the carrier sheets. The sheets emerge from the furnace bright and are unloaded carefully to prevent surface damage.

Finishing

Cold rolled annealed sheets up to .078" thick are skin passed to remove all kinks and dents and to prepare the sheet for flattening, except in the case of sheets intended for extremely difficult forming operations. The latter are shipped without skin passing and flattening. Skin passing causes a very slight reduction in the thickness of a sheet, not exceeding 1%.

Standard cold rolled sheets are flattened by means of an hydraulic stretcher leveler. The limits are from .018" to .250" in thickness, up to 60" in width, up to 179" in length. Sheets harder than ¼ hard are not stretched.

Tempered sheets are flattened by means of two standard type roller levelers. The limits of the larger machine are 20 to 60 inches in width, .025" to .187" thick if soft but up to .093" if ½ hard. The small machine limits are 20 to 48 inches in width, .021" to .050" thick if up to ¼ hard but .025" to .050" if ½ hard.

The last step in the production of sheet is to shear to width and length. Three plate-type shears are used for this purpose. Two machines cut thicknesses up to .187" and lengths up to 156", while the third machine cuts up to .250" thick and up to 184" in length. Two rotary shears are also available for cutting circles from sheets. One machine has a capacity of from .031" to .250" in thickness in 11¾" to 62" diameter circles; the other machine has a capacity up to .050" in thickness in 5" to 30" diameter circles.

CHAPTER VIII

PRODUCTION OF COLD ROLLED STRIP

First Annealing

The hot rolled strip coils from the Merchant Mill are open-annealed in a rotary hearth furnace, under reducing atmosphere containing about 7% $CO+H_2$, at a furnace temperature of 1700° F., for a total time of approximately 70 minutes. Coils are charged by means of a suitable lifting bar and are so placed in the furnace as to avoid direct flame impingement. When in the furnace, the strip is seated on rider bars, to prevent contact with the refractory hearth. When discharged, the metal is quenched by dropping into a 2% aqueous solution of denatured alcohol.

Pickling

The annealed and quenched coils are recoiled loosely, and the strands separated by means of spacer hooks. Thus prepared, the coils are loaded on racks for subsequent pickling in the Cold Drawing Department, using the solutions described in Chapter IX.

After pickling, the strip-loaded racks are withdrawn, and rinsed over a suitable drain with water. They are then dipped for a few minutes in a 2% ammoniacal solution to neutralize any traces of acid which may remain.

Surface Conditioning

Any surface imperfections evident in the pickled strip which will not roll out in the subsequent processing are removed by spot grinding. For this purpose, power driven abrasive coated cloth grinding wheels 16" diameter x 3" face are used; the abrasive is No. 60 emery grit.

Breakdown Rolling

For the breakdown or roughing operations, four stands of 2-high mills 16" x 22" are used either as a 4-set tandem or as two 2-set tandems depending upon the thickness of the strip involved and the cold rolling reduction desired. The delivery speed of the first stand is from 50 to 100 feet per minute; the second stand, 75 to 150 feet per minute; the third and fourth stands, 100 to 200 feet per minute. The top roll in each stand is ground with .003" crown, whereas the corresponding bottom rolls are flat across the barrel.

The overall reduction in roughing operations is of the order of 50 percent. In the case of operating all four mills in tandem, such reduction is accomplished by reducing approximately 20 percent with the first stand, 16 percent with the second, 10 percent with the third and 4 percent with the fourth.

Intermediate and Final Annealing

The intermediate and final annealing operations are carried out in five horizontal continuous type, electrically heated, controlled atmosphere bright annealing furnaces with variable speed drives. The controlled atmosphere is nitrogen containing 10 to 12 percent hydrogen dried to a dew point of about minus 60° F. The time-temperature cycle for any particular lot of strip depends upon the thickness of material to be annealed. The following data are illustrative of the time-temperature cycles used:

Thickness of Strip	Temperature of Heating Zone-°F.	Speed of Travel Feet per Minute	Time of Exposure In Heating Zone Minutes
.005"	1650	7	3.3
.010"	1650	7	3.3
.015"	1700	7	3.3
.025"	1725	6	3.8
.034"	1800	4.5	5.1
.050"	1850	4	5.7
.070"	1925	3.5	6.6

Finishing Rolling

For finishing rolling, six mills of various types and sizes are used.

A single stand 2-high mill 16" x 22" is used for rolling strip in widths from 4" to 18" in thicknesses from .015" to .250". The top roll has .003" crown; the bottom roll is flat across the barrel. The delivery speed is from 125 to 250 feet per minute.

A single stand 2-high mill 12" x 18" is used for rolling strip in widths from 3" to 12", in thicknesses of .015" to .250". The top roll has .003" crown; the bottom roll is flat across the barrel. The delivery speed is from 75 to 150 feet per minute.

A single stand 2-high mill 10" x 13¾" is used for rolling strip in widths from 1" to 8" in thicknesses from .005" to .093". The top roll has .003" crown; the bottom roll is flat across the barrel. The delivery speed is from 63 to 126 feet per minute.

A single stand 2-high mill 6" x 8" is used for rolling strip in widths of ¼" to 4", in thicknesses of .005" to .093". The top roll has .003" crown; the bottom roll is flat across the barrel. The delivery speed is from 48 to 96 feet per minute.

For temper rolling on any of the above mills, the top roll is .002" - .003" concave and the bottom roll flat across the barrel.

A 4-high, reversing, "pull-through" or tension type mill, in which the rolls are not driven but rather the movement of the strip is accomplished entirely through power driven reels, is used for rolling strip in widths from 2" to 6½", in thicknesses from .005" to .030". The working rolls are 3" x 8½" and both the top and bottom rolls are flat across the barrel. The delivery speed is variable from 95 to 508 feet per minute.

A larger 4-high mill similar to that described in the preceding paragraph is used for rolling .005" in widths from 8" to 12", .006" in widths from 7¾" to 12", .007" in widths from 7½" to 12", .008" in widths from 7" to 12", .009" in widths from 6" to 12", and .010" to .030" in widths from 5¼" to 12". Both the top and bottom rolls are ground flat across the barrel. Delivery speed is variable from 700 to 1,400 feet per minute.

All cold rolls are of forged steel heat treated to a hardness of approximately 100 Scleroscope. Rolls are ground in a conventional roll grinding machine to the required dimensions. The desired high surface polish on the rolls is accomplished after the rolls have been set up in the mills; this is done by hand lapping with No. 320 emery cloth.

Tolerances

General tolerances maintained on finshed strip are as follows:

Thickness (inches)	Tolerance (inches)	
.005 - .012	+ 0	-.0005
.015 - .050	± .001	
.056 - .078	+ .001	-.0015
.093	± .0015	
.109 - .125	± .0025	
.130 - .156	± .003	
.171 - .250	± .004	

Cold reduction required to produce various tempers and the corresponding hardness values are as follows:

Temper	% Cold Reduction	Hardness (Rb)
Soft	0	61-68
Skin Hard	1 to 3	69-73
¼ Hard	3 to 7	74-82
½ Hard	7 to 12	83-89
¾ Hard	12 to 17	90-93
Hard	17 to 27	94-97
Full Hard	Above 27	98 min.

Protection of Surface in Final Cold Rolling

Every possible care is exercised to prevent scratching and other superficial damage to the surface of strip while cold rolling or otherwise processing the metal. Machine oil thinned with kerosene is introduced on the strip, which also passes through felt wipers before entering the finishing mills.

Rolls of wrapping paper cut to width are used in such a way as to introduce a layer of paper between each layer of metal in each operation requiring re-coiling. When it is necessary to move coils with the crane, brass tools are used to avoid scratching.

Finishing

After the rolling operations have been completed, the strip, other than that specified to be supplied in tempered condition, is annealed in the continuous furnaces previously mentioned.

The next operation after temper rolling or final annealing, as the case may be, is slitting the strip to the required width. Two conventional type rotary gang slitters are used. Coils are processed singly through each of these machines and the number of cuts per coil is limited to five for thicknesses up to .050" and to two for thicknesses from .050" to .250".

The resulting coils of strip are flattened and straightened using two conventional breakers which are not unlike roller levellers in design. Each has two interchangeable heads of different sizes. Strip is drawn through each machine by means of a power reel. The limitations in respect to width and thickness of strip handled by each head are as follows:

	Large Head	Small Head
Width	¼" to 12½"	¼" to 5½"
Thickness	.015" to .065"	.003" to .014"

Strip supplied in coils is boxed after the breaker operation. If straight lengths are desired, the coils are sent to the cut-off machines.

Two machines are used for cutting to specified lengths. One is an automatic machine wherein a pair of feeder rolls hands the metal to the knives; the other is a manually operated machine.

"Cut-to-length" strip is flattened by means of a hydraulic stretcher providing the temper is not over ¼ hard; tempered strip over ¼ hard is flattened in a multiple roll machine.

CHAPTER IX

PRODUCTION OF COLD DRAWN PRODUCTS

Cold Drawn Rods and Other Solid Sections

Cold drawn rounds are produced in sizes from ½" diameter to 1¼" diameter, inclusive, in steps of 1/32"; from 1¼" diameter to and including 3" diameter in steps of 1/16"; from 3" diameter to and including 3½" diameter in steps of ⅛"; and from 3½" diameter to and including 4" diameter in steps of ¼".

The hot rolled rounds for the production of finished sizes from ½" diameter to 2-7/16" diameter, inclusive, are hot rolled 3/32" to 7/32" oversize to allow sufficient stock for overhauling and for the proper amount of cold reduction; for finished sizes from 2½" diameter to 4" diameter, the oversize allowance is 11/32" to 13/32".

The hot rolled rounds received from the Merchant Mill are first straightened in a conventional cross-roll straightening machine. This is followed by machining one end of each round to a size approximately 1/16" less than the finished diameter for a distance of 5" to 7" in order to enable the round to enter the dies in the subsequent drawing operation; this is known as "pointing."

Rounds to finish ½" diameter to 2-7/16", inclusive, are then overhauled by removing approximately 1/32" on the diameter by centerless grinding; rounds to finish 2½" to 4", inclusive, are "skinned" or rough turned ⅛" to 3/16" on the diameter followed by centerless grinding a further 1/32" on the diameter.

The pointed rounds are then annealed in a continuous type, radiant tube, controlled atmosphere bright annealing furnace. The time-temperature cycles are dependent upon the diameter of the rounds to be annealed. For example, 1" diameter rounds receive an overall exposure in the hot zone equivalent to approximately 30 minutes; for 2" diameter rounds, this time interval approximates 60 minutes. The heating zone is maintained at 1700° F. The controlled atmosphere is provided by an external gas producing unit using natural gas; the gas-air combustion in this unit is controlled so that the effluent gaseous mixture contains about 13 percent carbon monoxide plus hydrogen with no free oxygen present.

The annealed rounds are "flash" pickled in a solution made up as follows:

Sodium Chloride (Salt)	2500 lbs.
Sodium Nitrate	2400 lbs.
Sulphuric Acid - 60° Bé	5000 lbs.

Add water to make 5000 gallons of final solution.

As mentioned in the comments under Sheet Pickling, a minimum of 5 g.p.l. of copper is maintained in the solution for the purpose of facilitating pickling. The solution is operated at 180 - 200° F. When the acid content has decreased to about 2 percent by weight corresponding to about 30° Bé, it is discarded and a new solution is made up. The expression "flash" pickling denotes a short time immersion of the order of 10 to 15 minutes.

Any surface defects present in the rounds are removed by spot grinding with hand-operated, motor driven grinding wheels. This is followed by a second "flash" pickle and then the rounds are lime coated by dipping in a hot lime slurry. The purpose of the lime coating is to aid the cold drawing lubricant in maintaining a lubricating film on the surface of the rounds as they are passing through the drawing dies.

The rounds are next given one pass on the drawbench, the reduction being equivalent to about half the overall reduction in cross-sectional area required to produce the finished size desired. The overall cold reductions are from 15 percent to 30 percent, the smaller percentages being applicable to the larger diameters and the larger percentages being applicable to the smaller diameters. The rounds, as they enter the drawing dies are flooded with a lubricant made up of 50 percent wire drawing grease and 50 percent paraffine oil. The rounds are again "flash" pickled and lime coated, then drawn one pass to the finished size required.

Two drawbenches are used for these operations; one is of 50,000 lbs. capacity which handles sizes from ½" diameter to 2-15/32" diameter, inclusive, and the other is of 200,000 lbs. capacity which handles the larger sizes up to and including 4" diameter.

Drawing speeds vary according to the size of the work. The following table is illustrative of those normally used:

1/2"	to	15/16" dia.	at 60 ft./min.
1"	to	1-1/2" dia.	at 43 ft./min.
1-9/16"	to	1-15/16" dia.	at 35 ft./min.
2"	to	2-5/16" dia.	at 25 ft./min.
2-3/8"	to	2-3/4" dia.	at 17 ft./min.
2-13/16"	to	4" dia.	at 15 ft./min.

Both carbon steel and tungsten carbide dies are used for drawing. The entry angle in the dies, or angle of approach, is 50° included; the entry angle to the working face of the dies is 22° included; the exit angle is 30° included. The working face or bearing for sizes under 1" diameter is ¼"; for sizes 1" to 1½" diameter, it is ⅜"; for the larger sizes up to 4" diameter, it is ½".

The cold drawn rounds are straightened using a conventional cross-roll straightening machine.

Rounds that are to be supplied in the stress-relieved condition are temper annealed for 18 hours at 575° F. in two electrically heated, car type furnaces. No special furnace atmosphere is provided. The rounds are then cut to the required length and prepared for shipment.

Rounds that are to be supplied in the annealed condition are annealed in the continuous, controlled atmosphere furnace previously mentioned and for the time-temperature cycles there indicated. After annealing, the rounds are again straightened, then cut to length and prepared for shipment.

The following are the standard diameter tolerances for cold drawn rounds:

Size	Plus	Minus
1/2" to 15/16" incl.	0	.002"
Over 15/16" to 1-15/16" incl.	0	.003"
Over 1-15/16" to 2½" incl.	0	.004"
Over 2½" to 3" incl.	0	.005"
Over 3" to 3½" incl.	0	.006"
Over 3½" to 4" incl.	0	.007"

The production procedures for cold drawn hexagons, squares and flats closely parallel the foregoing procedure for cold drawn rounds.

Cold Drawn Tubular Sections

Cold drawn seamless tubing is produced from extruded tube shells. The standard sizes are from ½" O.D. to 6" O.D. in steps of 1/16"; the wall thicknesses are from .020" to ⅜", the lower end of the range not being applicable to the larger diameters and the upper end of the range not being applicable to the smaller diameters.

The cold reduction equipment for processing tubing comprises both conventional drawbenches and units known as tube reducing machines.

There are four drawbenches, viz., a single chain bench of 20,000 lbs. capacity, a double chain bench of 50,000 lbs. capacity for each chain, a single chain bench of 100,000 lbs. capacity, and a single chain bench of 200,000 lbs. capacity.

The 20,000 lbs. bench is used for drawing sizes 1-1/16" O.D. and smaller. For the size range 11/16" to 1-1/16" O.D., the drawing speeds are from 20 to 40 feet per minute; for sizes ⅝" O.D. and under, the drawing speeds are from 40 to 60 feet per minute.

The 50,000 lb. double chain bench is used for drawing sizes from 1⅛" O.D. to 3" O.D. inclusive. For the size range 1⅛" O.D. to 2" O.D., the drawing speeds are from 20 to 50 feet per minute; for the size range 2" O.D. to 3" O.D., the drawing speeds are from 15 to 30 feet per minute.

The 100,000 lbs. bench is presently not in use.

The 200,000 lbs. bench is used for drawing sizes over 3" O.D. The drawing speeds vary from 1 to 60 feet per minute depending upon the O.D., wall thickness and reduction for the particular drawing operation involved.

There are two tube reducers, viz., one 3½" machine and one 1½" machine. These are used not only for the production of certain sizes of finished tubing but also as roughers in combination with drawbenches for finishing.

Finished tube sizes above 2½" O.D. are produced by conventional drawbench practice only; sizes 2½" O.D. and under are produced either directly on the tube reducers or by conventional drawbench practice or by a combination of tube reducers and drawbenches for finishing.

To illustrate the production of tubing by conventional drawbench practice and by tube reducer practice, the production of 2" O.D. - 16 ga. using each of these procedures is described below.

For the conventional drawbench practice, the extruded tube shell size is 3¼" O.D. x ¼" wall. The shells, as received from the Extrusion Department, are first pickled in the same solution as used for the solid sections previously described.

Any surface defects present are removed by hand grinding with power driven grinding wheels. This is followed by "flash" pickling after which one end of each tube is pointed by hot forging on a power driven hammer equipped with swedging dies; the points are 6" to 8" long.

The shells are then drawn on the 50,000 lbs. double chain bench one pass to 3" O.D. x .203" wall and a second pass to 2¾" O.D. x .165" wall. The drawing lubricant is dry wire drawing soap.

The resulting tubes are washed in a steam heated solution made up of 350 lbs. of tri-sodium phosphate in 3000 gallons of water.

The tubes are then annealed in the previously described continuous furnace using a temperature of 1700° F. and time exposure equivalent to about 30 minutes.

After re-pointing and washing, the tubes are drawn two additional passes on the same drawbench as before, the first to 2½" O.D. x .134" wall and the second to 2⅜" O.D. x .109" wall. The lubricant, as before, is dry wire drawing soap.

The operations of washing, annealing and re-pointing are repeated.

Following these operations, the tubes are drawn two more passes, on the same drawbench as before, the first to 2¼" O.D. x .083" wall and the second to 2⅛" O.D. x .065" wall. The lubricant, as before, is dry wire drawing soap.

The operations of washing, annealing and pickling are repeated.

The tubes are then drawn the final pass to 2" O.D. x 16 ga. using a mixture of 10 parts prime western beef tallow and 1 part castor oil as the lubricant instead of soap in order to improve the surface finish.

The finished tubes after washing are annealed at 1700° F. using a time exposure of about 20 minutes. They are then straightened in a cross-roll straightener, cut to length and prepared for shipment.

Both heat treated high carbon steel and tungsten carbide dies are used. The entry angle in the dies is 30° included; the entry angle to the working face is 22° included; the exit angle is 30° included. The working face, or bearing, is ⅛" for sizes up to 2½" O.D.; it is 3/16" for sizes 2⅝" to 4" O.D.; and it is ¼" for sizes over 4" O.D.

Mandrels are likewise heat treated high carbon steel.

All dies and mandrels are chromium plated; the thickness of deposit used is from .004" to .006".

The tube reducer practice for 2" O.D. - 16 ga. commences with the same size of pickled and ground extruded tube shell, 3¼" O.D. x ¼" wall. The first reduction is to 2⅝" O.D. x .165" wall. The tubes are then washed and annealed as above. An added operation of straightening is required before the next reducing operation. The second reduction is to the finished size 2" O.D. x 16 ga. The lubricant used on the outside of the tubes for both reducing operations is in reality a coolant. It is a mixture of 1 part "Purosol" to 5 parts of water and is flooded on the tubes by means of a recirculating pump. The inside lubricant is Standard #5214 drawing compound which is pumped through the hollow mandrel rod. Following the final reduction the tubes receive the same finishing operations as indicated above for the conventional drawbench practice.

CHAPTER X

POLISHING

Abrasives

A synthetic aluminum oxide is the abrasive used in the initial fine grinding and rough polishing in grit size numbers ranging from 80 to 240. This abrasive is used for both built-up cloth wheels and cloth or paper belts.

Fine polishing is done with Turkish emery, a natural abrasive, in grit size number 180 used either as a cloth wheel or as applied to cloth or paper belts.

Finishes

Polished sheet is normally given a satin finish, which is a fine grind with a good lustre.

Polished tubing and rod may be given either a satin finish, or a mirror finish.

Polished flats, angles, half-rounds and other related shapes are given a satin finish.

Procedure

A satin finish is applied to sheets up to 0.093" x 60" x 186". Sheets up to 48" x 168" are polished on belt type Mattison machines. The cloth or paper-backed abrasive belts are 50" wide x 22' 6" long and travel at speeds of 2200 to 3200 ft./min. lengthwise of the sheet, while the table reciprocates parellel to the direction of belt travel at a speed of 30 ft./min. The sheets are given 3 passes on 80 grit (dry), 2 passes on 120 grit (dry), 2 passes on 150 grit (dry), and 3 passes on 150 grit using cottonseed oil.

If necessary, the sheets are spot ground between the 80 and the 120 grit dry grind, using 120 grit paper belts 4" x 46', travelling 4200 ft./min. to remove slight localized surface imperfections remaining after the 80 grit grinding passes.

Sheets wider than 48" or longer than 168" are polished on wheel-type machines. In this type machine, a table feeds the sheets past a revolving wheel which grinds a wavy pattern lengthwise of the sheet by virtue of a slight transverse oscillation built into the wheel machine. The table below lists the abrasives, speeds and number of passes used to produce a satin finish with the wheel type machines.

Grit No.	Abrasive	Type Wheel	Peripheral Speed of wheel-fpm.	Table Speed -fpm.	No. Passes
80	Aluminum oxide	Cloth-dry	3800-7500	60	4
–(Spot grinding as required to remove surface imperfections)–					
180	Turkish emery	Cloth-dry	3300	60	4
180	"	Cloth-tallow	1900	60	4
180	"	Brush-oil	2600	100	½
180	"	" "	2600	60	1½
180	"	" "	1900	100	2½
180	"	" "	1900	40	½

Tubing which is to be given a satin finish on the outside surface is first ground circumferentially on a conventional belt grinding machine. On this machine the tube is pressed against the belt and advanced past it by means of leather rolls, which also serve to keep the tube rotating. The belt travels at 6000 fpm., while the tube is fed across the belt face at the rate of 16 fpm. The tubing is first ground using three passes with 80, 120 and 240 grit cloth belts. It is then polished longitudinally on the wheel type sheet machines using 180 grit Turkish emery and tallow on a built-up cloth wheel. The tubes must be rotated by hand to expose the surface for this final polishing step. The 18" diameter by 45" wide wheel rotates at a peripheral speed of 2600 fpm., while the table travels back and forth at 40 fpm. A wavy pattern is produced by the oscillating action of the wheel. The tube size limitations are from 3/16" to 5" OD in lengths from 5' to 32' long.

A satin finish on the inside surface of tubing is produced on a belt-type inside tube grinding machine. This machine has a set of rolls to support and rotate the tube being ground. A narrow cloth abrasive belt is passed through the tube and made endless with a splicing patch. The belt is pressed against the inside surface of the tube by means of a rubber boot inflated with air. Pressure control is obtained by varying air pressures. The steps in grinding to a satin finish require passing the boot back and forth through the rotating tube while using 80 grit and 100 grit belts traveling at 6400 fpm. and a final 180 grit belt moving at 4000 fpm. Tubing between ⅝" ID and 4½" ID up to 25' in length is within the capacity of the inside tube grinding machine.

Tubing with a mirror finish on the outside is produced by grinding with 80, 120 and 240 grit cloth belts on the belt grinding machine, and then finishing longitudinally on the wheel type sheet machine with

No. 180 emery cake on a Triplex cloth wheel followed by passes using No. 4 green stainless rouge on a canton flannel buffing wheel. The 18" diameter by 45" wide wheel used rotates at a peripheral speed of 8500 fpm., while the table travels back and forth at 40 fpm. Tubes from 3/16" OD to 4" OD and from 5 to 22 feet long up to 150 pounds are given this finish.

Rod is finished with a satin or mirror surface in a manner similar to that described for the outside surface of tubing. Flats, angles, half-rounds and other related shapes are given a satin finish using the wheel-type polishing machines.

CHAPTER XI

MACHINING

In the machining operations the important factors are:

1. The use of sturdy machines to facilitate a rigid setup of tools and work.
2. The use of accurately ground and smoothly finished tools.
3. The use of cooling or cutting compounds in amounts sufficient to keep the work well flooded.

Machining Stock

Forgings are generally of round or rectangular cross section and may be tapered longitudinally. Hot rolled products are of a variety of cross sections such as round, rectangular, angular and hexagonal.

The oversize allowances for machining are given below:

Allowance for Finished Machining of Hot Rolled Products

Size in.	Rounds	Flats, Squares and Hexagons
Up to ⅞ incl.	⅛ in. dia. over	1/8 in. on each side
1 to 1⅞ incl.	⅛ in. dia. over	3/16 in. on each side
2 to 2⅞ incl.	⅛ in. dia. over	3/16 in. on each side
3 to 4½ incl.	⅜ in. dia. over	3/16 in. on each side

The oversize allowance for finished machining of forgings is from ¾ in. to 1 in. on the diameter for rounds, ⅜ in. to ½ in. on each side for rectangular cross sections, and for other shapes is dependent, in addition to the above, on the finished cross section.

Tool Selection

Three types of tools are used in the various machining operations performed in the machine shop:

1. Cemented carbide tipped tools are used in machining operations permitting high cutting speeds.
2. Cast non-ferrous, high speed steel, or super high speed steel tipped tools are used in machining operations run at intermediate cutting speeds.
3. Forged tools of high speed steel are used in general purpose machining at low speeds and heavy feeds.

Tool Design

The cutting tools used are, in general, the same as for other tough metals having comparable mechanical properties. The important differences are that true-rake angles are ground slightly larger back from the cutting edge and clearance angles are ground smaller to provide maximum support for the cutting edge. Tools are ground with a fine finish or are honed to obtain maximum tool life between grinds.

Cooling and Cutting Compounds

Two central reservoir systems are available with delivery and return lines to each machine. One system delivers a coolant made up with 1 part soluble oil to 50 parts of water; the second system delivers a solution made up of 1 part used machine oil to 1 part sulphurized cutting oil.

The sulphurized cutting compound is used in most tapping operations. It is thoroughly removed from machined pieces and from all chips in order to avoid contamination of the metal in subsequent exposure to heating to elevated temperatures in fabrication, in service, or in remelting as process scrap. Removal is accomplished by soaking for 20-30 minutes in a cold 10% solution of sodium cyanide.

Turning and Boring

Heavy cuts with fine feeds are used in preference to light cuts and heavy feeds. Speeds are reduced for boring as distinct from turning operations because of lower cooling and lubricating efficiencies, and limitations on size and rigidity of the tool.

Rods up to 4½" in diameter are rough machined in a bar peeler, over 4½" are rough turned in engine lathes. In first operation work, where subsequent machining is to be done, a semi-smooth finish is furnished with an oversize allowance of between 1/16" and ⅛" on the diameter. Where straightness is a factor, the run-out over the length is controlled by "whipping" the rod, an operation performed by machining on centers with light to medium cuts at heavy feeds, with a reversal of the rod in the lathe after each pass of the tool over the length, repeating until down to size.

Rods are finish machined by making the last pass at a maximum feed of 0.015" per revolution with a tool having a nose radius less than the feed. This finish pass produces a "phonograph record" surface which is readily filed smooth and to size.

Lathes used in turning products such as valve stems and pinion shafts are 22" x 8' to 30" x 41' driven by 15 HP to 30 HP motors and 42" x 27' with a 40 HP drive motor.

The cuts, feeds and speeds tabulated below are based on cutting dry. Speeds are increased 20-25% when using coolant or cutting compound.

Cuts, Feeds and Speeds for Lathe Turning with High Speed Steel Tools

Depth of Cut (inches)	1/32			1/16		
Feed (inches)	.008	1/64	1/32	1/64	1/32	1/16
Speed (Ft. per min.)	168	139	118	121	104	60

Depth of Cut (inches)	1/8				1/4		
Feed (inches)	1/64	1/32	1/16	1/8	1/32	1/16	1/8
Speed (Ft. per min.)	110	68	48	34	57	39	29

Depth of Cut (inches)	3/8			1/2		
Feed (inches)	1/32	1/16	1/8	1/32	1/16	1/8
Speed (Ft. per min.)	52	34	24	49	31	21

Increase speed 25-35 per cent when using cast non-ferrous tools.

Drilling

Standard twist drills as furnished by drill manufacturers are used for general purpose drilling. This type of drill has an included angle of 118° and a clearance angle of 12° to 15°. Drills with polished flutes are preferred. For maximum cutting speeds, heavy duty high speed steel drills are used for holes under ½ in. diameter, for ½" and up to 3" super high speed steel is used. Drills are kept sharp. The approximate feeds and speeds for various size drills are given in the table below:

Feeds and Speeds for Drilling

Drill Size in.	Speed Ft. per min.	RPM	Feed Per Rev. in.
1/16	50	3055	0.0015
3/32	50	2100	0.0020
1/8	50	1525	0.0025
3/16	50	1020	0.003
1/4	60	920	0.0035
5/16	60	735	0.004
3/8	60	610	0.0045
7/16	60	525	0.005
1/2	60	460	0.0055
9/16	60	405	0.006
5/8	60	365	0.007
11/16	60	335	0.008
3/4	60	305	0.009
13/16	40	190	0.010
7/8	40	175	0.011
15/16	40	165	0.012

Feeds and Speeds for Drilling - (continued)

Drill Size in.	Speed Ft. per min.	RPM	Feed Per Rev. in.
1	40	150	0.013
1⅛	40	135	0.014
1¼	40	120	0.015
1⅜	40	115	0.015
1½	40	102	0.015
1⅝	40	100	0.016
1¾	40	85	0.016
1⅞	40	80	0.016
2	40	75	0.016
2¼	40	65	0.016
2½	40	60	0.016
2¾	40	55	0.016
3	40	50	0.016

Holes larger in diameter than 3 in. are drilled with flat drills. Flat drills are ground with a 132° included angle, 12° to 15° clearance with chip breakers in the cutting edge. Flat drills are generally used with 0.005 in. feed at 80 ft. per min. speed. Coolant is supplied at the cutting edge of the drill.

A radial drill press with spindle speeds from 14 to 1010 rpm. and a 20 HP motor drive is used, in addition to the lathes, for drilling operations.

Reaming

Reaming operations are performed when a high finish and accurate size are required. Spiral fluted, high-speed steel reamers with narrow lands and well polished flutes are used. The reamers are kept sharp at all times. Flat reamers are used for holes larger than 2 in. diameter. Reaming feed is approximately twice the drilling feed for the same hole size; reaming speed is approximately one-half drilling speed. The table below gives approximate feeds and speeds for reaming.

Feeds and Speed for Reaming

Speed Ft. per min.	Hole Diameter in.	Feed in per Rev.	Metal to be removed in. dia.
25-35	⅛ to ¼	0.003-0.005	to 0.005
25-35	¼ to ½	0.005-0.009	to 0.008
20-30	½ to 1	0.009-0.020	to 0.012
15-20	1 to 2	1/32	1/64 to 1/32

Tapping

National standard, four-fluted, high-speed steel plug taps, with ground threads and 7° spiral flutes, and four fluted, spiral-pointed plug taps are used in machine tapping. The flutes are ground to give approximately a 15° lip angle and the tap is "backed off."

Tapping is done at a speed of 15 to 25 ft. per min. The taps are kept sharp so that clean, smooth threads are obtained.

Planing and Shaping

The setup for planing or shaping is the same as that for mild steel. Both roughing and finishing operations may be dry but an improved finish is obtained by use of the water soluble coolant. The goose neck type of planer tool is preferred for finishing cuts because the cutting edge is in line with, or behind the center line of, the clapper-box pin resulting in smoother cuts. The table below gives feeds and speeds used in production work.

Feeds and Speeds for Planing Heavy Work

Roughing Tool

Depth of Cut, in.	1/16	1/8	1/4	3/8
Feed, in.	3/32	1/16	5/64	3/64
Speed, Ft. per min.	25	25	25	25

Finishing Tool

Depth of Cut, in.	0.020	0.014	0.010
Feed, in.	11/32	5/32	3/8
Speed, Ft. per min.	25	35	30

Parting Tool

Depth of Cut, in.	0.005 to 0.010
Feed, in.	-
Speed, Ft. per min.	30

Milling

Milling chips tend to curl rather than to break up to fine shreds or powder. To facilitate the removal of the curling type of chip, milling cutters are ground with a back-rake angle of 10° to 15°. Coarse tooth cutters are preferred. Plain or barrel milling cutters are of the heavy-duty, spiral-fluted type. Alternate tooth or interlocking side millers are used for milling deep holes or for slitting. For narrow slitting, high-speed steel slitting saws with alternate teeth chamfered are most satisfactory. This type of circular saw is ground concave on the sides for clearance.

The surface speeds and feeds that are used in milling depend to a large extent upon the power and rigidity of the milling machine. For general purpose milling, cutting speeds of 50 to 65 ft. per minute, and feeds of 0.005 to 0.010 in. per tooth (depending on the depth of cut) are employed.

Since the essential purpose of the milling operation is usually extreme accuracy and smooth finish, it is necessary to sharpen cutters carefully and as frequently as may be required to keep the cutting edges sharp. The work is also kept flooded with a stream of coolant or cutting compound.