number of turns which different specimens will stand without breaking, while high-grade metal which has been carefully drawn, twists unevenly and uniformly, with no slivering and shows little difference in the number of turns on different specimens. It is, therefore, desirable to make at least three torsion tests, whereas one tensile strength test is sufficient to obtain an accurate measure of the strength.

In the appended Table No. 1 are given a series of tests which clearly illustrate the four general divisions into which the trolley wire of commerce may be divided by reason of difference in physical qualities. Specimens A—B—C having tensile strengths of 5,500 lbs. or higher, and torsion tests averaging about 13 represent wire lacking toughness, which has been given a high tensile strength by drawing. Specimens D—E—F having tensile strengths around 5,300 lbs. and torsion tests of about 15 are wires lacking both toughness and surface hardness. Specimens G—H—I having tensile strengths of about 5,100, but torsion tests of approximately 23, are typical wires in which the torsion has been obtained at the expense of tensile strength, while specimens X—Y—Z with tensile strengths over 5,400 lbs. together with torsion tests of 26 and even higher represent the best trolley wire which can be made at a reasonable price.

Of these four classes there is again a distinction in that the first two represent copper of an inferior grade which cannot be made the equal of the wires of the last two classes by any treatment in the rod mill. On the other hand, wires of the last two classes are both made from excellent copper, although specimens X—Y—Z are wires greatly superior in all respects to the preceding three. It is interesting to note that all of these wires have practically the same conductivity which shows clearly the fallacy of attempting to value trolley wire by conductivity and tensile strength alone as is so frequently done.

It is therefore, necessary not only to obtain high-grade copper, but also to secure the proper balance between tensile strength and torsion, as these two properties are correlated and increase in one, beyond a certain point, results in a proportionate decrease of the other.

The preceding remarks have shown the conditions under which wire must work and the qualities which are necessary to successfully meet these conditions. Attention must now be turned to the process of manufacture to determine how these qualities may be obtained and what defects of such processes injure the finished wire. For this purpose a brief review of the industry is necessary.

In the refining furnace the copper which is already at least 96 per cent. pure from the blister furnace is oxidized by air until a large part of the impurities have been removed and copper oxide is formed in considerable excess. Cuprous oxide is readily soluble in molten copper and acts as a powerful oxidizing agent by giving up its oxygen to any metallic bases present, so that an excess of oxide insures the presence of all metallic impurities in the oxide form. The excess cuprous oxide is then removed by burying a piece of green wood in the molten mass and covering the surface with charcoal. This process must be stopped within very narrow limits as over-reduction will throw the impurities back into the metallic state.

The influence of cuprous oxide has been studied by Mr. Patch, of the Detroit Copper Company; Dr. Edward D. Peters, Jr., who is without doubt one of the best authorities on the metal in this country, and by the well-known German authority, W. Hampe, among many others. Many of the impurities of copper have been found to be much more injurious when present in the metallic state than when in the form of oxides, and one effect of the cuprous oxide, as above mentioned is to convert these impurities into the comparatively inert and harmless form and so improve the quality of the metal. In large quantities, however, it is known to harden copper while at the same time causing it to become short or brittle and according to Hampe the presence of 1 per cent. produces a diminution in toughness.

It is therefore possible to so treat low-grade metal that it will have high conductivity although the large amount of cuprous oxide present greatly reduces the toughness. In purchasing copper for drawing trolley wire the manufacturer insists upon conductivity, but as a rule cares little for the other physical qualities, as he can obtain sufficient tensile strength by drawing. Lake copper possesses both high conductivity and excellent mechanical qualities, but this kind of copper costs from ⅛c. to ¾c. per lb. more than electrolytic. Why the latter should be inferior to lake is difficult of explanation, but experience shows that the general run of commercial electrolytic copper is by no means uniform in physical qualities and as a general thing is distinctly inferior to lake for wire drawing purposes. The cheaper price of electrolytic results in its use by many manufacturers although they frequently understand that the wire will be inferior.

The refined copper comes to the rod mill in bars weighing about 200 lbs. each, approximately ten of which are used in the manufacture of a mile of wire. These bars frequently have ridges along the sides, due to faults in casting and the surface is often covered with a layer of oxide. These bars are heated in the furnace until sufficiently soft for rolling and are passed through a series of rolls diminishing in size until a rod of the proper diameter is obtained. The rod is then cooled and drawn through dies, the rods being connected by brazing. The dies give the wire a dense hard exterior coating which increases its tenacity. As the strength obtainable is almost a direct factor of the work expended upon the wire, the smaller the size, the greater the tensile strength per square inch, so that the strength of the trolley wire is readily varied by changing the size of the rod and the number of dies.

One of the most serious defects occurring to wire at this point is from ridged bars as above described. Ordinarily the bar will not be sufficiently heated to dissolve the copper oxide on the surface, so that as the softened bar enters the first passes of the rolls the ridges are lapped over, enclosing the oxide scale. The subsequent passes and the drawing through the dies obscure this flaw almost entirely, but it remains a serious menace to the toughness and resistance to wear of the copper, as has been previously shown in remarks on the torsion test.

A second cause of trouble arises at the same point by overheating the copper in the furnace, in which case copper oxide is formed on the surface and quickly dissolved through the entire bar, thereby increasing the oxide content and tending toward the production of brittleness. Both of these dangers can be avoided by careful selection of the bars and by proper regulating of the temperature of the softening furnace.

As the production of the hard surface from drawing is at best a rather delicate operation, careless handling, uneven welding of the rods and unequal temperature of the wire while passing through the dies will all produce noticeable effects in the quality of the finished wire, so that care throughout the mill is absolutely necessary for the best results.

It therefore appears that the most efficient wire must possess not only high conductivity, but the maximum torsion and tensile strength possible in commercial copper and that to obtain this it is necessary first, to use high-grade copper and to prevent an excess of cuprous oxide entering it at any stage of the manufacture, and secondly, to select as perfect bars as possible and to observe extreme care in every treatment through which they pass. The question at once arises, can such wire be purchased at a commercial price? The writer must admit that this high-grade wire can not be obtained at the ordinary market price, but requires the payment of a premium of ½c. per pound. To produce wire of this grade, consistently the wire manufacturer must use the higher-priced Lake Copper and observe unusual care in its treatment so that he is justified in demanding a higher price. Experience in the use of this wire has shown conclusively that it is well worth the additional cost.

The appended Table No. 2 gives the results obtained upon 13 consecutive miles of trolley wire made from selected bars of Lake Copper. The tests were made upon each mile of the wire and the results show the great uniformity obtainable by proper care. It should be said in this connection that this