What are the, COMBINED EFFECTS OF TEMPERATURE AND VERY HIGH PRESSURE ON METALS?

The inception of high-pressure, high-temperature operations has opened many new avenues of investigation. The author discusses the possible effects of both on electrical resistance, ductility, hardening, and other mechanical and structural properties of metals.

by R. B. Fischer

One of the greatest potential fields for metallurgical research was opened when means were developed to apply high temperatures to materials under very high pressures. The background for the subject was built over the years by the integrated efforts of many individuals, but the development of apparatus by General Electric Co. fired the imagination of reseachers.

To those whose routine efforts are devoted to producing and marketing a metal product, there will be an understandable reserve about getting excited over this subject, since the high-pressure, high-temperature cells available to date are small. On the other hand, the Engineering Supervision Co. recently offered to provide considerably larger cells than those used to date. No technical barriers seem to bar the construction of larger cells when needed; therefore, there is little cause for concern on this particular point.

More important is the question of what can be accomplished by the use of combined temperature-pressure operations. Here researchers, now adequately equipped, are striving for answers. Their efforts will bear close observation, because the results might bring about a drastic change in materials as we now know them. The use of high-temperature, high-pressure apparatus in studies of materials is so vast as to appear limitless. Facing this scope of possibilities, can one honestly maintain doubtful reservations about the potential of this subject? Advances are being made already in developing basic knowledge which will, at a minimum, feed back to help understand and improve present processes.

Effects on melting temperatures

For practical purposes, the melting temperature of a metal has long been treated as a constant. For example, temperature calibrations are based sometimes on the melting point of a pure metal. In the future, it is likely that the question, "What is the melting temperature of iron?", will be recognized by technologists as demanding the counter question, "At what pressure?". Recent work described by Strong[1] illustrates the point. Strong's work and others[2, 3, 4, 6], has been used in Fig. 1 to show the relationship of melting temperatures versus pressure for several metals.

At this time, the Clapeyron-type equation, $dT/dP = T_m(\Delta V)/L$, is useful for predicting the effect of pressure on melting temperatures. The expression dT/dP is the change of melting temperature with a change of external pressure. If the proper units of T_m, the melting point at zero pressure, ΔV, the volume change on melting, and L, the latent heat of fusion, are substituted in the equation, fairly good estimates can be made. For those metals that expand on melting, an increase in pressure generally results in a higher melting temperature, since pressure tends to prevent expansion (and melting). This situation is overcome by increasing the temperature to the extent that melting can occur. In general, an opposite relationship exists for those metals that contract on melting; an increase in pressure lowers their melting temperature.

There is a question as to the extent that these relationships hold as higher pressures and temperatures, not yet attainable in present apparatus. It is known for bismuth, that the melting temperature decreases with increasing pressure to a point where the metal transforms into a new solid phase. This new phase has a melting temperature curve which then increases with pressure. The melting temperature curve for rubidium increases with pressure to a maximum and then decreases, but this is unusual, as Strong[1] has indicated. For other metals, melting temperatures have been found to increase or decrease as expected up to the limits of present apparatus. Will these relationships continue; will phase transformations occur; and what are the ultimate results of pressure application to metals? These are interesting questions for conjecture, but what can be done with the knowledge already at hand on the effects of pressure on melting temperature of metals?

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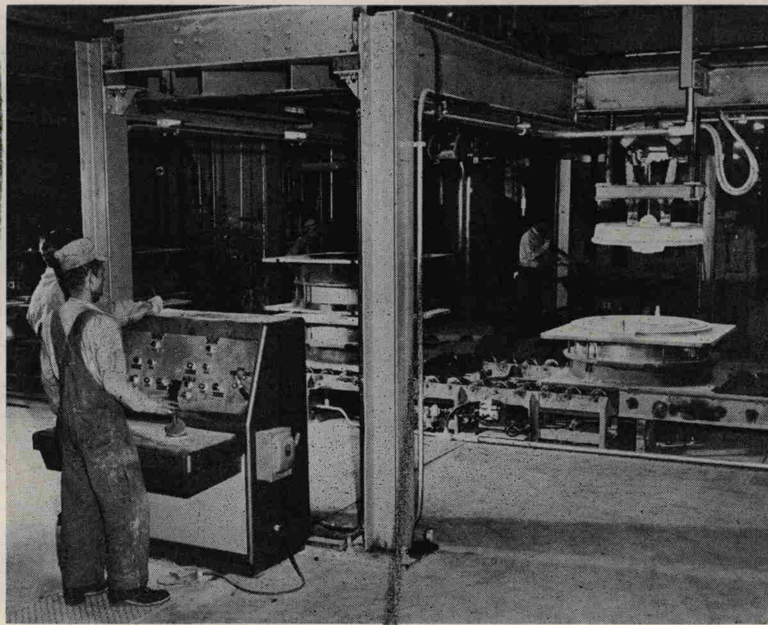

Right, view of operations . . . wheel at left has just been poured. Crane at left removes the cope, while crane at right removes a previously-poured wheel.

Left, a close-up view of the pouring tank and cover.

Applied to steel mills

Application of the pressure-pouring process to the casting of semi-rolled shapes has been the subject of considerable investigation by Griffin's metallurgists, even prior to U.S. Steel's interest in the technique. The objective has been the elimination of high-cost primary rolling mills and soaking pits.

Many types of steel have been used in Griffin's experiments; they have varied in carbon content from 0.10 to 1 pct, and have included stainless types and boron steels. Perhaps the greatest interest has been in casting slabs, and Griffin has cast slabs measuring 5x37.5 in. x 15 ft from low-carbon steels. Stainless steel slabs also have been cast, and tube rounds up to 6 in. in diam have been cast without segregation. With reference to billets, experimental work has shown the possibility of casting 3x3 in. x 30 ft shapes from 150-ton heats in 40 min. Thus, pouring is rapid and stripping can also be accomplished with considerable speed.

These semis have been characterized by good surface finish, practically eliminating the necessity of scarfing and other surface treatment. One problem is that of center-line shrinkage; in practice it will probably necessitate a sealing of the ends of the cast shape in order to prevent oxidation stringers from forming. Because of this shrinkage, finished rolled shapes can not be cast. However, it appears likely that subsequent rolling can produce steel products of a quality equivalent to present commercial practice.

The difference between pressure pouring and present techniques appears to lie both in capital costs for steel-mill equipment and in production costs encountered in soaking pit, rolling, and scarfing operations. A further saving would result from increased yield of usable metal, resulting from an elimination of hot tops and cropped ends of semi-rolled shapes.

U.S. Steel's pilot-plant work in the next two years should answer the question of whether pressure pouring can be applied commercially to steelmaking.