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A SPECIALTY PLATE PRODUCER'S EXPERIENCE WITH CONTINUOUS SLAB CASTING[1]

by

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S U M M A R Y

Lukens specializes in heavy plate production, based on an electric melting shop. A continuous casting machine has recently been installed for the production of slabs with a maximum size of 216 x 30.7 cm, the largest of their kind in the USA.

The paper begins by describing the factors that were taken into consideration when the proposal to install continuous casting was discussed. The final decision rested on the anticipated improvement in melt-to-ship ratio and operating efficiency.

After a short description of the plant, consideration is given to the personnel planning and selection aspects of continuous casting.

Metallurgical and operating considerations are next discussed. Argon stirring was introduced and, after a number of trials, a tundish with a fused-silica shroud was adopted.

Some of the special features of the Lukens machine include two independent hydraulic pressure systems, hydraulic bolting, a cavity-type dummy-bar head, and a special dummy-bar carriage.

Intensive study was made during the early period of operation of a number of parameters, notably water flowrate, casting speed, casting powder, slab exit temperature, and sulphur content. Operating schedules were set up following the investigation of these parameters. The steel slabs produced have excellent surface and internal qualities and physical properties equal to or better than those of conventionally cast and rolled slabs.

A number of problems were encountered during this period. They included speed and electrical load problems in the roller apron and succeeding segments (solved by additional instrumentation), breakage in the withdrawal rolls (not yet solved, but still under active study), under-lubrication of the rollers in the roll segments, and failure of heat exchangers (due to too low a water velocity in the tubes).

Lukens Steel Company, founded in 1810, is the oldest steel company in the United States. During its more than 160 years of operation, the firm has earned the reputation as "The Specialist in Plate Steels." Located in Coatesville, Pennsylvania, Lukens specializes in plate steel production, devoting its entire manpower, facilities, and knowledge to the development, production, and marketing of steel in plate form.

The company produces carbon, alloy, armor, and clad steel plates, heads, and plate shapes to the widest range of specifications and in the largest sizes in the United States, and, with an annual ingot capacity of over one million tons, ranks as the fourth largest producer of plate steels in the country.

Lukens supplies its plates and plate products internationally to builders of equipment for industries ranging from petroleum, chemical, and nuclear to shipbuilding, power generation, and construction, as well as to manufacturers of transportation equipment, presses, machine tools, and paper-making equipment.

The Electric Melt Shop at Lukens has an annual capacity in excess of 600,000 tons (544,000 metric tons). At the heart of this operation are three furnaces — two of 110-ton (100 metric ton) capacity and one of 155-ton (140 metric ton) capacity. The latest addition to this complex is a continuous-casting machine capable of producing a slab 85 inches x 12 inches (216 cm. x 30.7 cm.) — the largest cross-section slab produced in the United States.

Three factors had to be considered by the company in making its decision to install a continuous-casting facility.

The first was Lukens' desire to maintain its role as a specialty steel producer. The company had no desire to add commodity items to its product line in order to justify the installation.

The second was the reduction ratio. Lukens has built its reputation on its ability to produce the heaviest plates in the steal industry. Since a six-to-one reduction ratio from a cast slab to a finished-quality plate had been established as a guide line, it was not practical to employ continuous casting in heavy plate production; lighter plates would have to justify the machine.

The third was the availability of sufficient tonnages of liquid steel to support such an installation. Lukens has no BOF or Kaldo units. Although its Melt Shop has a rated capacity of 52,000 tons of steel per month, the potential liquid steel available for casting was determined to be a maximum of 24,500 tons (22,200 metric tons) per month because of furnace cycle and product mix limitations.

On the positive side, it was evident that continuous casting offered several opportunities for unusual improvements in our production performance: (1) bottom poured, killed steel ingots would be replaced by continuous-cast slabs; (2) double-converted ingots (requiring slabbing prior to rolling to plate) would be replaced; (3) slabbing operations would be removed from a mill capable of rolling finished plate; and (4) the rolling of a conditioned slab section would be more rapid and predictable. These potential advantages were sufficient to justify serious study and subsequent installation of our continuous-casting facility.

The facility has several sections available. To date, three different cross-sections (65 inches x 7 inches, 85 inches x 9 inches, and 85 inches x 12 inches (165 cm. x 17.7 cm., 216 cm. x 22.8 cm., and 216 cm. x 30.7 cm.) have been poured in steels having a maximum of .42% carbon and in steels having a maximum of 1.60% manganese. Fine-grained steels were also considered adaptable to continuous casting. It was further agreed that only plate gauges over 3/8 inch to 1-1/2 inches (9.5 mm. to 38 mm.) inclusive would be considered in the economic evaluation. The 85 inch x 12 inch section (216 cm. x 30 cm.) was similarly excluded.

Two basic objectives were established for this installation. The first was an improvement in our total melt-to-ship ratio of 4.7%, that ratio being shipped tons divided by ingot tons. In order to achieve this objective at our normal ingot production, it would be necessary to cast 24,500 liquid steel tons (22,200 liquid steel metric tons) per month with an improvement of 18.6% in the melt-to-ship ratio of those tons.

The second objective was improved operating efficiencies.

After careful study of all these factors, it was determined that a continuous-casting facility would be economically feasible for Lukens.

It is not our intent to describe all the details of the continuous caster and associated equipment. Figure 1 is a simplified plan view showing the electric furnaces and continuous caster. Figure 2 is a cross-section of the continuous-casting installation. Only selected items will be discussed because of their general interest. Some detailed information is supplied on our "Facts List" (Figure 3). Subsequent papers on specific aspects of the Lukens installation will be issued in the future.

Engineering and design studies followed the decision to go ahead with the program, and an order for the new facility was placed with suppliers in May, 1969. Ground was broken on July 1, 1969. The facility went into operation on a simulated cast basis on December 22, 1970, and the first cast was made on January 18, 1971, capping a construction and installation period of only 19 months.

Long-range planning was largely responsible for the relatively short building program; it had provided for a large portion of the required casting building during the installation of the third electric furnace in 1964. An eighty foot span (24.4 meter span) between major building columns was constructed in the south wall of the teeming aisle. This span, central to the furnace shop,

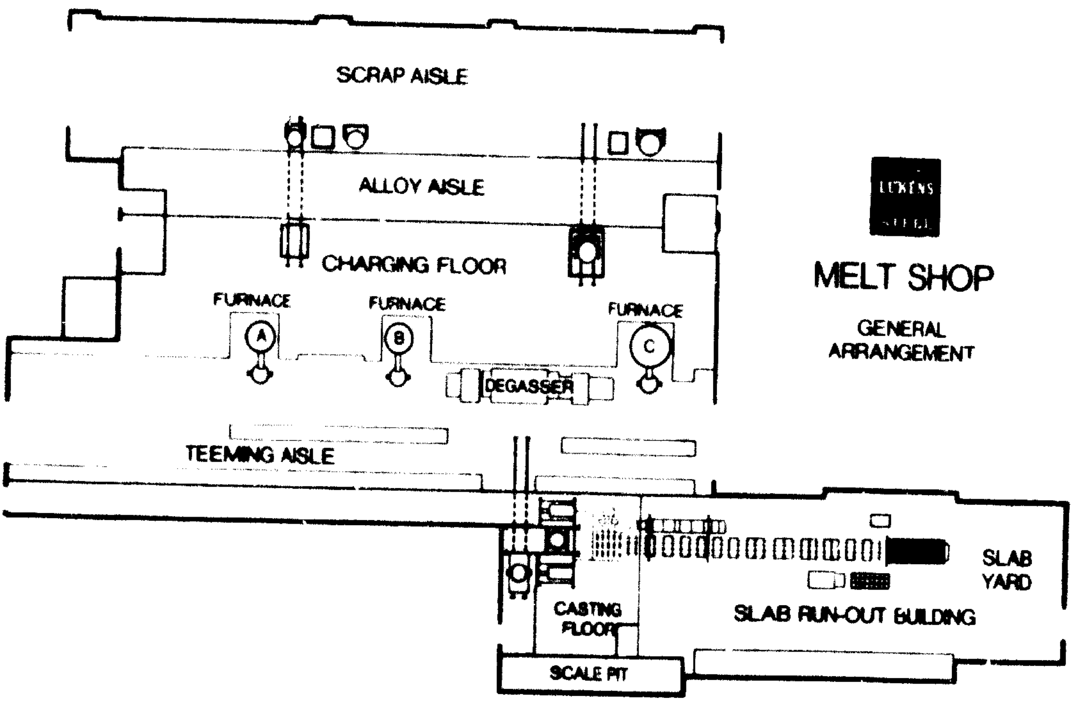


Figure #1 Simplified Plan View of Melt Shop and Continuous Casting

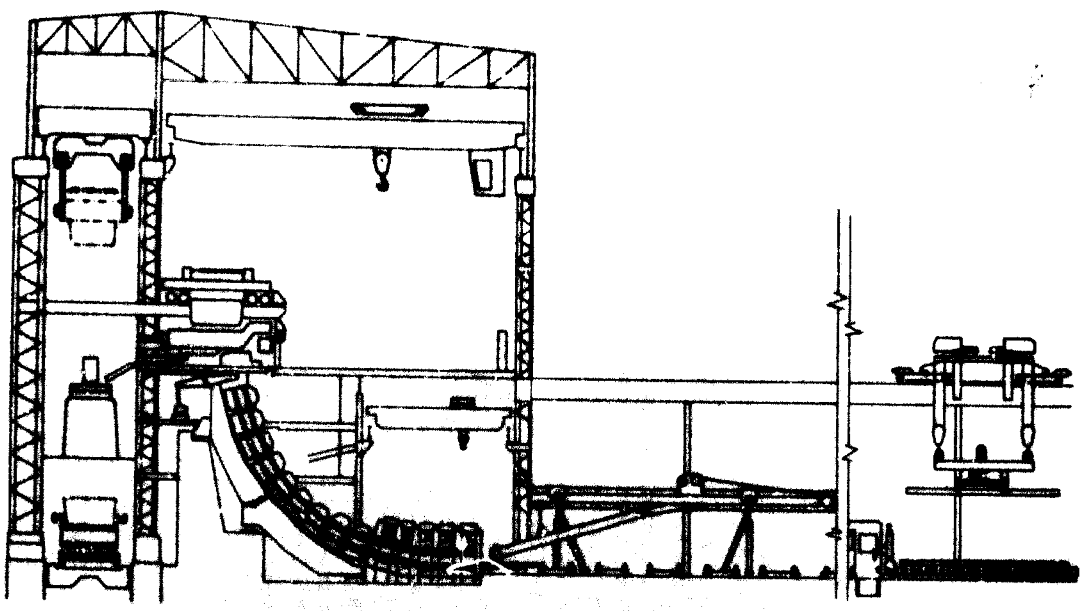


Figure #2 Cross Section of Continuous Casting Installation

Slab Casting Machine Facts and Information

Number of Strands	1
Mold Sizes	65" x 7", 85" x 9" and 85" x 12" (165 cm. x 17.7 cm., 216 cm. x 22.8 cm., and 216 cm. x 30.7 cm.
Mold Type	Curved
Heat Sizes	110 Tons and 155 Tons (100 metric tons and 140 metric tons)
Specified Casting Rate	3 Tons per Minute (2.7 metric tons per minute)
Casting Duration	60 Min. Max.
Turn Around Time	120 Min. Max.
Designed Casting Speed Range	10 - 100 ipm (25 - 250 cm. per minute)
Dummy Bar Insertion Speed	10 - 200 ipm (25 - 500 cm. per minute)
Machine Radius	40 Ft. Constant (12.2 meters)
Roller Apron Gauge Control	Hydraulic Bolting against Shims
Roller Apron Segment Removal	Hydraulically sidewise to car on curved track
Dummy Bar Type	Universal with Cavity Type Head
Slab Imprinter	Rotary Type with 3/4" Characters (19 mm.)
Cutting Torch	Stationary Type with two Cutting Heads
Hot Metal Weighing	At Pouring Car -- 500,000 lbs. Capacity (227,000 kg.)
Slab and Crop Weighing	Off Line -- Electronic Scale 100,000 lbs. Capacity (45,400 kg.)
Stirring Station	Rod Immersion -- argon gas
Ladle Control	Hydraulically actuated stopper rod
Mold Water	Closed Loop - Filtered, Softened and Treated
Spray Water	Recirculated - Filtered, Softened and Treated
Machine Water	Recirculated - Strained Raw Water
Hydraulics	Water based system
Cranes	Remote Controlled from Floor by Operating Personnel

Figure #3

is now the opening between the teeming aisle and the 100 feet wide x 110 feet long (30.5 meters wide x 33.6 meters long) casting machine building, which is large enough for a future second machine.

A 109 feet wide x 240 feet long (33.2 meters wide x 75.7 meters long) slab run-out building, large enough for two strands, was also constructed during the third furnace program. During the period between 1964 and 1971, this building functioned as an ingot-mold preparation building. Upon approval of the continuous-casting proposal, a 109 feet wide x 80 feet long (33.2 meters wide x 24.4 meters long) slab yard was added to one end of the slab run-out building. This yard is used for slab processing.

Proper planning also required that a number of the support facilities be placed on the far side of a small river that runs adjacent to the facility (Figures 4 and 5).

Personnel Planning and Selection

Throughout our continuous casting studies, it was obvious that the quality of personnel selected for the operation of the unit would have a great bearing on the success of the overall project. The strand casting process requires thorough physical and mental discipline, and the failure of any operator to adhere to an established operating procedure might result in serious losses in equipment and material.

The design of the equipment and the overall lay-out gave due recognition to the importance of the operating personnel. Upon management approval of the project in May, 1969, immediate steps were taken to formulate a personnel selection and training procedure. A committee was formed to plan and execute the selection and training of the people for the jobs created by the strand casting installation.

The efforts of this committee have been well documented in a paper presented to the American Iron and Steel Institute in May, 1970, by John E. Muhs, Facilities Planning Engineer. The results of these efforts have been outstanding. The operating organization has performed in an outstanding manner. (Figures 6 and 7).

Metallurgy and Operating Considerations

Efforts were made to gain as much practical knowledge as possible related to various metallurgical and operating considerations. Prior to the start-up, a number of simulations of the actual casting operation were made in the pouring aisle.

The melting as well as the ladle and stirring practices established during this development period formed an excellent foundation for our current practice for producing continuous cast slabs.

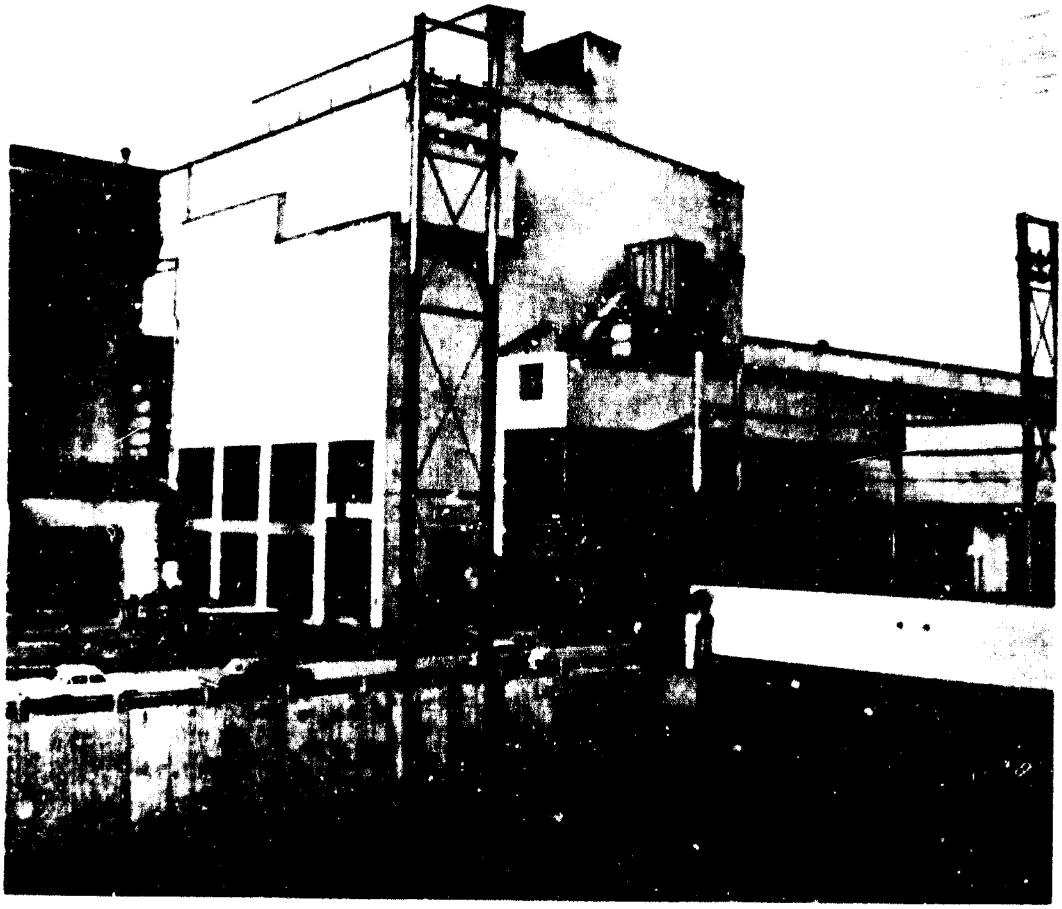


Figure #4 Picture of Cooling Towers

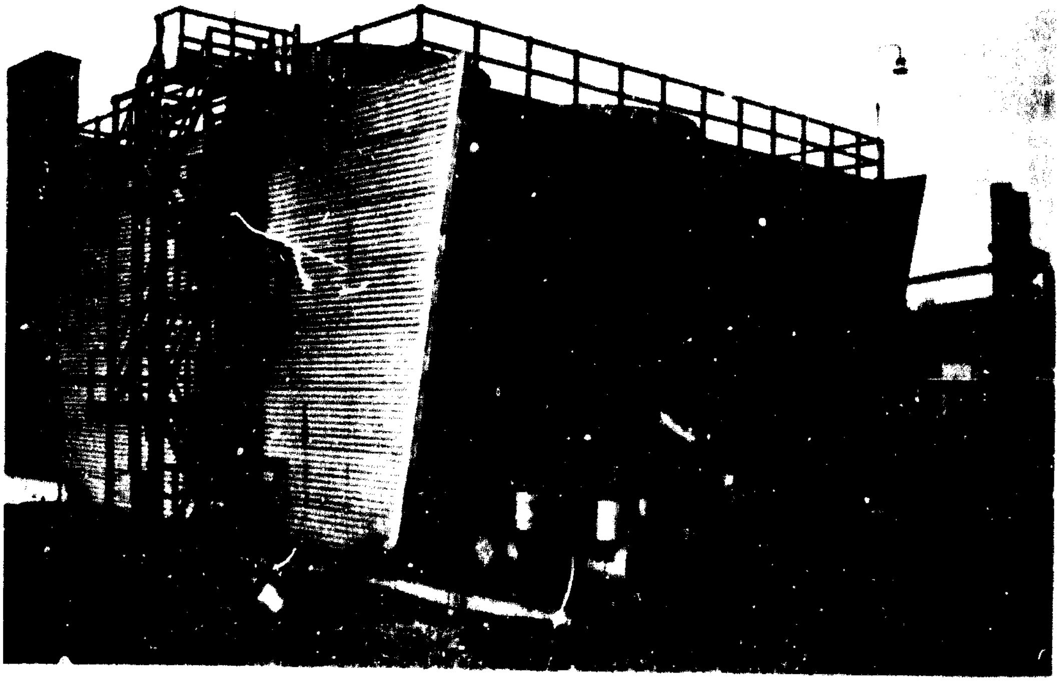


Figure #5 Picture of Continuous Caster from Across Brandywine

Personnel Requirements (per turn) for Continuous Slab Caster

Supervision

1 Foreman per turn (total of 4) plus Supervisor - Continuous Casting

Direct Labor

Job Title	Number of Personnel Required
#1 Operator	1
#2 Operator	1
#3 Operator	2
#4 Operator	1
Slab Cutter	1
Floor Boss	1
Total Personnel per Turn	7

7 men x 8 hours per turn x 21* turns per week = 1,176 manhours per week.

*21 turns per week consist of 20 operating and 1 maintenance.

NOTE: Operating personnel are considered responsible for all functions associated with the casting operation.

Figure #6

Personnel Requirements (per turn) for Continuous Slab Caster

Support Personnel

Mechanical Maintenance - 1 man per turn

Pipe Shop - 1 man per turn

Process Metallurgist - day turn only

Clerk - day turn only

Figure #7

Temperature considerations were an essential initial concern. Upon completion of the tap, the ladle is moved to a platform adjacent to the furnace to permit measurement of the slag depth and to take temperature measurements. At this point, two factors were recognized: (1) if the slag depth is less than five inches (127 mm.), about one inch (25.4 mm.) of insulating powder must be spread over the slag surface; and (2) should the top of the ladle temperature exceed the established standard aim by 15°F. (8.5°C.), the heat must be taken to the vacuum degassing unit for a brief cooling and mixing treatment.

An argon stirring station was installed as soon as possible following approval of the project. A series of trials were made to establish proper stirring procedures for our shop as well as proper rod construction and maintenance. These trials contributed markedly to the development of the installation as it now exists and to the operating procedure.

The argon stirring rod and disposable thermocouple are mounted vertically on two parallel pantographs. The stirring rod is similar in appearance to a ladle stopper rod. It is constructed of seven-inch (17.8 cm.) O.D. standard fireclay sleeves with four eight-inch (20.3 cm.) O.D. 70% alumina material, 12 inches (30.2 cm.) in length and tapered slightly toward the tip. The single argon gas orifice is 3/8-inch (9.5 mm.) O.D. Argon pressure at the orifice is 40 psi (.03 kg./mm.^{2}). When in stirring position, the rod is one foot (30.2 cm.) from the ladle bottom.

During use, the head will wear back to ultimate failure. The expected life of a rod is 18 to 20 heats, with the highest experience to date of 32 heats. Rod life is extended by the ability to repair flaws that develop during treatment and by maintaining a constant gas preheat on the head between heats to reduce thermal-shock failure. Operating data are given in Figure 9.

A normal heat would be taken directly to the argon stirring station where optimum treatment time is four minutes. If the top of the ladle temperature is slightly higher than desired, but not sufficient to warrant degassing, stirring can be extended to a maximum of six minutes. These procedures eliminate the need for additions of cooling scrap. From a quality point of view, we do not feel degassing is necessary for successful continuous cast slab production.

During stirring treatments, a minimum of three temperature readings is required. They are taken at one-minute intervals following the first minute of treatment. With these repeated temperature observations, we are capable of predicting the tundish temperature of the metal to an accuracy of $\pm$ 5°F. ($\pm$ 3°C.).

As soon as personnel who had been selected to man the continuous-casting installation were available, a tundish was installed in a steel weldment that bridged the teeming aisle. This installation had three objectives: (1) further refinement of temperature information; (2) familiarization with tundish pouring by the operating crew; and (3) additional information on tundish refractories and shrouds.

Heats were cast through the tundish and into the ingot molds during the trials with temperatures being taken in various locations in the tundish and mold. The data obtained through these simulations provided adequate guidance to direct the initial efforts when casting began.

Revisions were made in the original refractory design of the tundish lining during the pouring trials to improve performance. The crews also gained valuable experience in techniques of tundish clean-up and preparation. Figure 8 shows performance to date.

The loss of temperature during the trials was greater than that found in actual casting. Better than expected delivery times and better control of tundish preheat were the primary reasons. Diverted heats for improper temperature are well below 3%. The Time-Temperature Chart (Figure 9) indicates the current actual time cycle).

Our experimental tundish arrangement permitted thorough study of the shrouds to be used in the planned operation. Early tests indicated that none of the refractory shrouds was satisfactory for the pouring of high manganese steels. Development of acceptable shrouds received the highest priority. Severe erosion of fused silica shrouds to the point of failure was experienced, and a trial with a zirconia shroud was also unsatisfactory. Extensive testing with graphite-high alumina shrouds indicated excellent resistance to erosion, but severe clogging difficulties were experienced.

Fortunately, a superior fused silica shroud was developed by our supplier. This, combined with proper adjustment to shroud dimension, has made it possible to cast all carbon grades up to 1.60% manganese with one type of pouring shroud. The majority of the fine-grain heats are over 0.90% manganese. In addition, erosion from the high manganese counteracts the alumina clogging problem.

Casting Machine Features

The casting machine installed at Lukens was custom-tailored to meet the needs of a custom steelmaker. It contains two independent hydraulic pressure systems, employs hydraulic bolting, has a cavity-type dummy bar head, and a unique dummy bar carriage.

A 1000 psi (.7 kg./mm.^{2}) hydraulic system is used to raise and lower the segment and straightening rolls and tundish preheat burners. A 3000 psi (2.1 kg./mm^2) system raises and lowers straightening pinch roll sets as well as the roller-apron sets. It also furnishes the force required to raise the dummy-bar rack.

These systems are filled with a mixture of 95% water and 5% biodegradable fluid. The initial high cost of this type of system is more than offset by lower operating costs and better pollution control. Pipe ruptures during early periods of operation drained the systems several times. Had we used a fluid other than water, we would have encountered serious pollution problems and high replenishment costs.

Hydraulic bolting is employed to maintain pressure for the desired strand openings. It reduces the chances for roll breakage, affords ease of maintenance, makes clearing of breakouts less difficult, and allows more rapid mold size changes. Although hydraulic bolting has met all expectations thus far, it does require close attention by maintenance personnel.

Continuous Slab Caster Statistics
(Based on First Year's Performance 1/13/71 - 1/13/72)

Item	Anticipated Performance	Actual Average Performance to Date	Best Performance to Date
Stirring Rods			
Tonnage Throughput/Rods	1134 (1030 metric)	2328 (2120 metric)	4256 (3870 metric)
Number of Casts/Rods	9	17.5	32
Tundish Life			
Tonnage Throughput/Relinings	1890 (1720 metric)	7887 (7170 metric)	17,423 (15,870 metric)
Number of Casts/Relinings	14.2	59.3	131
Mold Powder			
Pounds/Ton of Steel Cast	1 (.5 kg./metric ton)	1.5 (.75 kg./metric ton)	
Ladles			
Number of Casts/Ladle	20	16	-
Molds			
Number of Casts/Re-machining	150	242.5	256
Number of Re-machinings/Life	6	?	-

Figure #6

Time/Temperature Profile
Typical 150-Ton Metric Ton) Carbon Steel Heat for Continuous Casting
Casting Speed: 3 Tons/Minute (2.7 Metric) (Average)

85 Inch x 9 Inch Section (216.7 cm. x 22.8 cm.)

	Total Time (minutes)	Time Interval (minutes)	Temperature
Initial Tundish Temperature	4	4	2775°F. (1524°C.)
Equalization Temperature - **No abnormal changes in temperature following this initial time lapse.	9	5	2790°F. (1532°C.)
Slab at Exit of Withdrawal System	35	26	1600°F. (871°C.)
Empty Ladle (Finish Cast)	51	16	
TOTAL CASTING TIME	——	51 minutes	——

** Contrary to simulation studies, actual operation has never shown a severe temperature drop toward the end of the casting operation. Great improvement in tundish pre-heat combined with sufficient casting speed probably accounts for this.

Figure

The cavity-type dummy bar on the facility requires less preparation time than other types and eliminates re-assembly between casts. This type also offers a minimum of front-end crop loss (See Figure #10).

The capability of the dummy bar rack to move to one side following disconnect reduces required turn-around time and eliminates the need for extensive heat shielding.

Although hot-metal processing and casting are undoubtedly the most intriguing parts of the continuous-casting operation, there are several elements of our slab-processing operation which are considered worthy of mention.

Our layout includes a stationary double torch located a sufficient distance from the withdrawal roll to permit an entire 155-ton (140 metric ton) heat poured in the 85 inch x 9 inch slab section (216 cm. x 22.8 cm. slab section) to lay on the runout table without interfering with the operation of the casting machine. This type of installation has eliminated any problems which might have been associated with a traversing cut-off torch. It also has permitted us to cut the as-cast section to lengths as short as 75 inches (190 cm.). Although the minimum cut length of our slabs for the rolling mill is 35 inches (89 cm.), a large number are required between 75 inches (190 cm.) and 125 inches (318 cm.). The capability to perform this operation in-line has eliminated substantial cutting labor and equipment costs.

A rotary imprinter was designed into the facility to assure product identity on short slabs. A 12-inch (30.2 cm.) diameter wheel with 3/4 inch (19 mm.) characters attached is supported by a machine frame. An air cylinder, providing continuous pressure, pushes the housing and wheel against the side of the slab. As the wheel rotates against the slab, numbers are imprinted on the slab about every three feet (91 cm.).

The refinement of the length measuring device, which employs a rotating disc in the roller table prior to the cut-off torch, enables slabs to be cut to an accuracy of plus one-half inch, minus zero inches (12.7 mm.) on the run.

All cranes in the area, including the ladle hoist, are remotely controlled by operating personnel located in their normal work areas. This has eliminated the need for specialized crane operators. It has been a very satisfactory operating procedure.

A slab inspection and weighing station permits the accurate weighing of the slabs as soon as they have been cut. All slabs are held for a minimum of eight hours to permit adequate cooling prior to inspection. Slabs are inspected on an elevated platform which permits inspection of both top and bottom surfaces.

Early Operating Observations

Operations were started with the 65 inch x 7 inch (165 cm. x 17.7 cm.) mold in the machine. Chemistry was limited to .10/.15% carbon, .30/.60% manganese coarse grain deoxidation and all heats were poured with a submerged nozzle and casting powders. Because of an initial lack of water and temperature control refinement, a high rate of slab conditioning was experienced.

Figure #10 Picture of End Scrap on Cast Slab Leaving Withdrawal Rolls

After pouring eighteen heats in the 65 inch x 7 inch (165 cm. x 17.7 cm.) mold, the results were encouraging enough to place the 85 inch x 9 inch (216 cm. x 22.8 cm.) mold into operation. Our greatest demand is for this section. The 85 inch x 12 inch (216 cm. x 30.2 cm.) mold was installed after approximately eight months of experience with 85 inch x 9 inch (216 cm. x 22.8 cm.) section. Approximately 5000 tons (4550 metric tons) were successfully cast in this section before returning to the 85 inch x 9 inch (216 cm. x 22.8 cm.) section.

The effect of various casting techniques on the slab surface quality was studied constantly. After several hundred heats were cast, the results were summarized and standard practices temporarily established. Considered in their relation to surface quality were water flow-rate, casting speed, casting flux, slab exit temperature, and sulfur content.

Our studies found that lower water flow-rates for similar casting speeds and temperatures resulted in better slab surfaces. Seven hundred and thirty gallons per minute (two thousand seven hundred and eighty liters per minute) became the break-off point in the initial study. Only those heats with similar casting practices and within existing standards are reflected in the associated chart (Figure 11). The optimum casting speed and water flow-rate was established at 0.12 gallons of water per pound steel cast (1.0 liter of water per kg. of steel cast) 240 gallons per ton, 720 gallons per minute (1000 liters per metric ton, 2,780 liters per minute) at a casting speed of 30 inches (76 cm.) per minute three tons per minute, (2.7 metric tons per minute). This provides a slab temperature at the straightener of 1570°F/1630°F. (854°C/888°C.). Although 0.12 gallons per pound (1.0 liters per kg.) is well below the 0.15 gallons per pound (1.25 liters per kg.) experienced by others with similar equipment, it has been extremely successful at Lukens.

The effect of sulfur (Figure 12) is as might be expected: the higher the sulfur, the poorer the surface.

Surfaces on fine-grain high-manganese steels have been excellent. This is not the case in low-manganese fine-grain steels. The decreased fluidity of the low-manganese metal has caused some casting-speed difficulty because the metal freezes in the shroud.

A carbon steel having a carbon range of .32/.38% and manganese range of .60/.90% has produced the best slab quality. Only 3% of the slabs produced have required any conditioning at all.

Short longitudinal cracks are the primary reasons for scarfing. These cracks are one inch or less, but may extend five or six feet if proper casting procedures are not maintained. Slab surface has been found to deteriorate as the tonnage cast through an 85 inch x 9 inch (216 cm. x 22.8 cm.) mold exceeds approximately 30,000 tons (27,300 metric tons).

Casting powders have provided much discussion among casting groups. To find out more about them, tests were conducted to relate the fusion characteristics of the powder and its chemical composition with the relative slab surface quality.

The most desirable powder was found to be done with a fusion temperature of approximately 2200°F. (1204°C.). Fusion time and phase change temperature

Water Flow-Rate versus Slab Conditioning

(Heats without Deviations)

85" x 9" Section

All Carbon Steel

Gallons per Minute	**Conditioning % Top	% Bottom	% Heavy Cracks
Below 730* (2760 liters)	12.1	0.9	0
730 and above (2760 liters)	5.8	2.8	29.0

* Currently operating at approximately 720 gallons (2725 liters) per minute.

** % refers to surface area of cast slab.

Figure #1

Sulfur versus Slab Conditioning

Sulfur	** % Conditioning Top	** % Conditioning Bottom	% Heats Requiring 100% Scarf
Below .021	8.0	2.4	None
.021/.025	12.8	7.4	6.5
.028 and above	17.3	13.2	16.7

** % refers to surface area of cast slab.

Figure #12

were found to be critical. The best results were obtained with powders that changed from a slag to a fully vitrified composition with a temperature increase of 50° to 100°F. (27.8° to 55.5°C.).

The quality of the cast product has naturally been of prime concern. Some difficulty was experienced in achieving the desired chemistry, particularly with silicon aims, until adequate control of slag deactivation and volume were achieved and proper stirring times were developed. Care must still be exercised in handling fine-grain heats. It was found that more aluminum additions were needed to maintain acceptable final aluminum levels in the low carbon grades (below 0.11% carbon) than were required for ingot pouring (.025% total aluminum).

Chemical segregation checks were run throughout the width and thickness of slab sections. Complete testing was done only as new grades or mold sizes were cast, but the results were consistent on all mold sizes and grades tested. Regardless of carbon or manganese levels, a very significant reduction in chemical segregation was found to exist in the plate product, regardless of carbon or manganese levels as compared to plate produced from ingots.

The internal quality of the plate has been as exceptional as the surface quality of the plate. Melt-type defects have been reduced significantly in all mills. In fact, there has been an 80% reduction in melt defects for all carbon-steel grades continuously cast compared to similar grades conventionally cast.

Physical properties of plates rolled from continuously cast steel have been found equal to or better than plates of similar chemistries rolled from the conventional ingot.

All data previously discussed has been on carbon steel. Other grades experimentally cast to date include #1, #2, and #3 as shown in Figure 13.

Problems Encountered

The start-up of a facility of this type is not without its problems. It may be interesting to note, however, that we did not encounter any metallurgical difficulties that warrant discussion here.

The problems we did encounter were in the areas of equipment operation, maintenance, and/or design.

Soon after the start of operations, speed and electrical load problems developed in the roller apron and succeeding segments. A recording ammeter and a second speed recorder were installed to detect deviations from the normal. Any difference between the two speed recorders indicates slippage of the strand or another unusual operating condition. When a significant deviation occurs, it is recognized immediately and the source of the deviation is determined. This modification has prevented a number of serious difficulties. It has, in addition, permitted more rapid development of proper maintenance procedures.

Potential Alloy Steels for Continuous Casting

	C	Mn	Si	Ni	Cr	Mo	Other Elements
Steel #1 -	.12/.21	.70/1.00	.20/.35	-	.40/.65	.15/.25	.03/.08 V .01/.03 Ti .0005/.005 B
Steel #2 -	.10/.19	.90/1.25	.15/.30	-	.40/.60	-	.02/.10 V .25/.40 Cu
Steel #3 -	.21 max.	.55/.80	.15/.30	-	.50/.80	.45/.60	-
Steel #4 -	.17 max.	.40/.65	.15/.30	-	.80/1.15	.45/.60	-
Steel #5 -	.17 max.	.40/.65	.50/.80	-	1.00/1.50	.45/.60	-
Steel #6 -	.18/.26	.90 max.	.15/.30	-	-	.45/.60	-

Figure #13

Among the serious problems avoided was potential machine damage when a guide was torn loose from one of the segments in the spray chamber. The loose guide would have gone undetected had not a sharp increase in motor current been registered on the ammeter.

Breakage in the withdrawal rolls was another problem. The continuous casting machine has nine 25-inch (63.5 cm.) and one 31-inch (78.8 cm.) diameter rolls that straighten the slab and control strand speed. Between these rolls are 16-1/2 inch (42 cm.) rolls to prevent strand bulging; they also transfer the dummy bar. The original 25-inch (63.5 cm.), 31-inch (78.8 cm.) and 16-1/2-inch (42 cm.) rolls are internally cooled to protect bearings from overheating. The original 25-inch (63.5 cm.) and 31-inch (78.8 cm.) rolls were forged AISI 4140 steel and contained W-shaped grooves which were expected to reduce surface cracking of the rolls. (It was believed heat checking was the failure cause of smooth rolls on other machines.)

After several failures of the grooved rolls they were replaced by smooth rolls; these, however, failed in a short period of time and are not considered satisfactory.

Two potential solutions to this problem are being considered. First is a sleeve roll, now in use. The sleeve comprises a centrifically cast AISI 4340 steel shrunk over a spiral-grooved mandrel with water circulating between the sleeve and the mandrel. The second is a hollow roll, which is presently being fabricated at Lukens, and which will also be water-cooled. To date (February, 1972) only one 16-1/2-inch (42 cm.) roll has failed. No rolls within the spray chamber have failed, but some show heat checking in lower zones.

Although considerable study has been given this problem, it would be premature to attempt to state the solution.

Weekly roll inspection by ultrasonic testing, however, has allowed us to monitor roll cracking and to schedule roll replacement prior to failure. Before settling upon the ultrasonic technique, many test suggestions were made, including magnetic-particle and dye-penetrant testing.

Magnetic-particle and dye-penetrant testing procedures were found to be time-consuming, and the test data hard to interpret. Ultrasonic testing is performed by introducing pulse echo sound-waves through 30° slope shoulder by means of a 60° shear-wave transducer (1 MHz); by mode conversion to a refracting wave, this ultrasound passes through the entire roll face and locates vertical discontinuity indications which might be present. To assure complete penetration, preliminary studies were made using a double transducer — one at opposite slope shoulders — employing a through transmission method, commonly referred to as a "pitch and catch", which verified the ability for satisfactory sonic responses. All indications are verified by local dye-penetrant methods since slight horizontal linearity errors are introduced ultrasonically in this length.

The ultrasonic examination on a scheduled down-time basis has prevented premature roll failure in the course of operation. It has predicted the possible failure of nine rolls, all of which have been replaced. We are limited with this test to a three-inch (76 mm.) area below outside diameter roll due to the shoulder configuration; however, additional scanning could be performed through the roll hub if necessary. This inspection procedure, initiated several months following start-up, has enabled us to study more intelligently the critical area of strain in the machine; it also aids in design evaluation and assignment of interchangeable rolls to more or less critical locations.

An expensive lesson in lubrication engineering was learned several months after start-up. During one of the few breakouts experienced during the early months of operation, the No. 3 roll segment was removed for clean-up, and the bottom rollers were found to be locked tight. Upon disassembly of the bearing boxes, very little grease was found, but large quantities of scale and water were present. Further examination of the roller apron showed that scale and water had entered the bearing boxes and had frozen the rollers in the No. 2, No. 3, No. 4, No. 5, and No. 6 roll segments. Scale and asbestos rope were discovered behind the heat shields, and the rollers in No. 7 and No. 8 roll segments were bound in a fixed position. Complete disassembly of the affected components was necessary.

In due time the machine was reassembled and casting resumed with the following changes: the lower half of the heat shield on all bottom rollers was removed to prevent scale from being trapped between heat shield and chock; all bearings were hand packed full; lubrication was increased in frequency from one pump-cycle every 40+ minutes of machine operation to one cycle every 3+ minutes, 24 hours a day (regardless of operation); and the lubrication system was modified by installing singlepoint distribution boxes on bottom rolls and doublepoint boxes on top rollers.

Three large heat exchangers in the mold water system failed after about six months of operation when pitting developed in the tubes on the machine water side. The probable cause was too low a water velocity in the tube which established galvanic cells in areas of deposit. The machine water pump output was measured at about 1500+ gpm (5700 liters per minute) as opposed to a rated pump output of 2640 gpm (10,000 liters per minute). Adjustment of pump impellers made up the difference. Other remedial action included the removal of some tubes to create higher tube velocities and the purchase of a borescope to periodically inspect the interior of heat exchanger tubes. A recent heat-exchanger inspection showed no visible pitting and very few deposits.

Conclusions

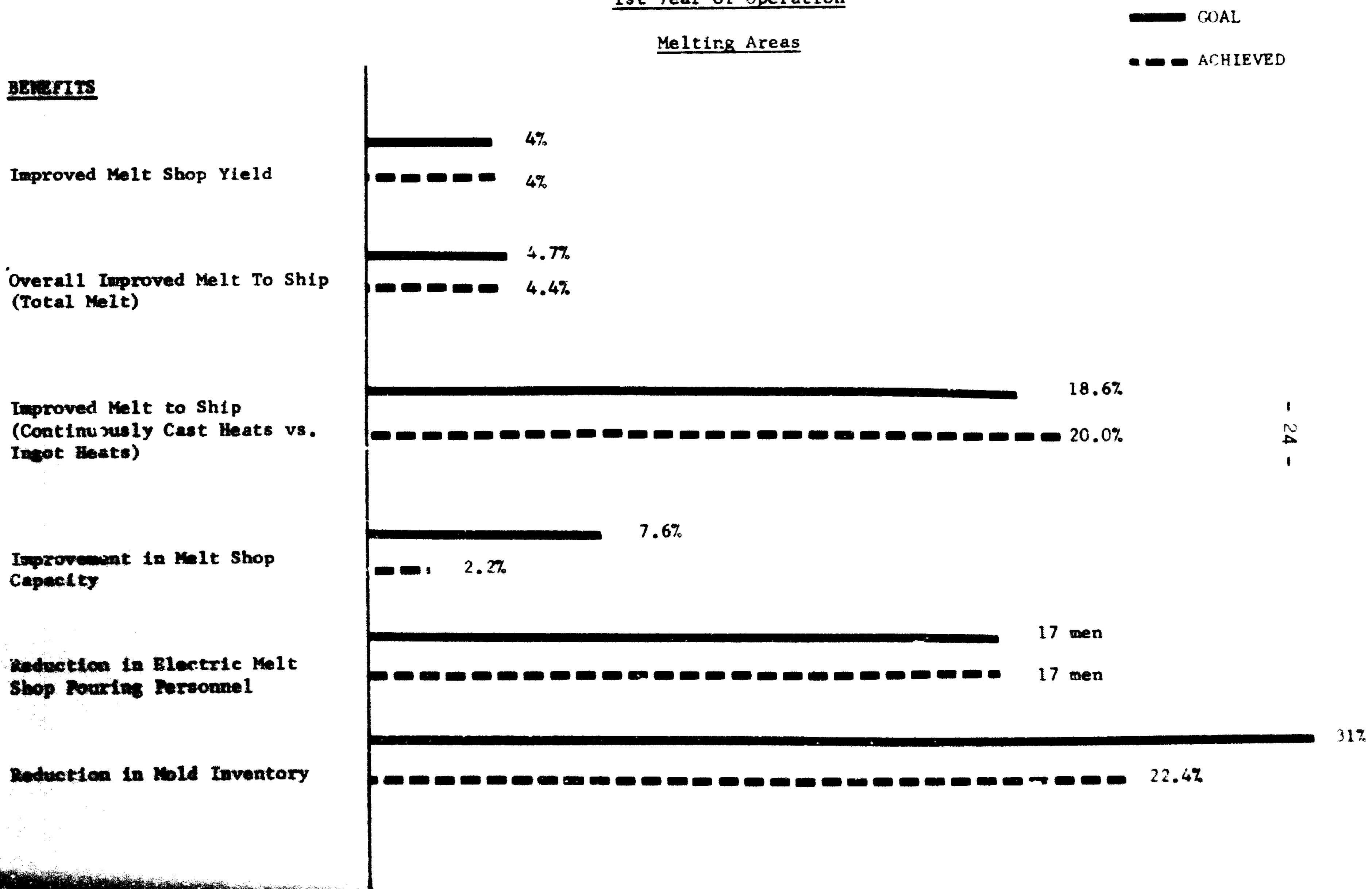
Major new facilities often reduce earnings during the first year of operation. This has been the case where others have installed continuous casting. We are proud to say that our facility began contributing to earnings in the second quarter and overcame start-up costs before the end of the year.

The following charts illustrate some of our achievements as related to the specified objectives (Figures 14, 15, 16).

Benefits from Continuously Cast Slabs

1st Year of Operation

Melting Areas



Figure

Benefits Attributable to Continuously Cast Slabs

Steel Conditioning Areas

- 11% Reduction in Manpower
- Lower Transportation Charges
- Less Required Supplies and Utility Services

Figure #15

Benefits from Continuously Cast Slabs

Rolling Areas

Reduction in rolling mill hours due to:

reduced slabbing on 140-inch Mill....... 11%

slab section on 120-inch Mill........... 10% +

Improved provided plate yield....................... 4% (approx.)

Increase in rolled plate length..................... 15% (approx.)

Increase in average piece weight.................... 5%

Figure #16

During the first year of production, every grade of carbon steel planned for continuous casting was successfully cast. In addition, several high-strength low-alloy grades were successfully cast. The ambitious objective of casting 135,000 tons (123,000 metric tons) during the first year of operation was exceeded.

Product quality surpassed all expectations. The planned thru-put of our continuous caster during the initial year of operation represented only slightly more than 50% of the intended annual production. But goals shown in Figure 15 are based on a fully operational unit, and the fact that we achieved a 4% improvement in melt shop yield, an improvement of 4.4% in our overall melt-to-ship ratio, and a 2.2% increase in effective melting capacity during this initial year of operation was most gratifying. We are confident that this year's operations will surpass established objectives.

The successful casting of several of our heat-sensitive grades makes us quite optimistic about expanding the chemistry range to include an increasing number of alloy steels.

To date we have been rather rigid in our adherence to conservative ratios of reduction. However, studies indicate that considerable opportunities exist for application of continuous casting to heavier gauge plates.

Methods must be determined to permit more rapid section changes, and improvements in the predictable availability of hot metal for the unit must be made. We are confident these answers and many more will be found in the coming years.

In our experience, continuous casting has made a significant contribution to the specialty plate business. It will play a more important role in our manufacturing process in the years ahead.

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