ABRASION RESISTANT STEEL PIPING SYSTEMS FOR SLURRY TRANSPORT IN MINING APPLICATIONS

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ABSTRACT

Various metallurgical and material enhancements are available to transform steel pipe into high strength, abrasion resistant products, suitable for the transport of abrasive slurries encountered in mining applications. These enhancements include induction hardening of the interior pipe wall, in addition to utilizing pipe wall materials consisting of varying chemistries, such as encountered with bi-metallic, di-clad, and double wall piping systems.

Each type of system has advantages and disadvantages, both in the manufacturing processes as well as in their application for slurry transport of abrasive materials. The proper selection of component accessories, including the various configurations and alternate materials can provide the ultimate total system wear life expectancy.

Section 1 Typical Mine Applications

Steel piping systems are widely used in mining to convey the product, ore, and tailing slurries to the processing plant, as well as to recycle the debris medium back to the mining area. Slurries are a mixture of solid particles in a liquid medium. Steel piping systems are also utilized for backfilling the mine excavation areas utilizing sand fill, classified tailings, or paste fill. Steel piping systems are also widely utilized as drop shafts for conveying product from high elevations.

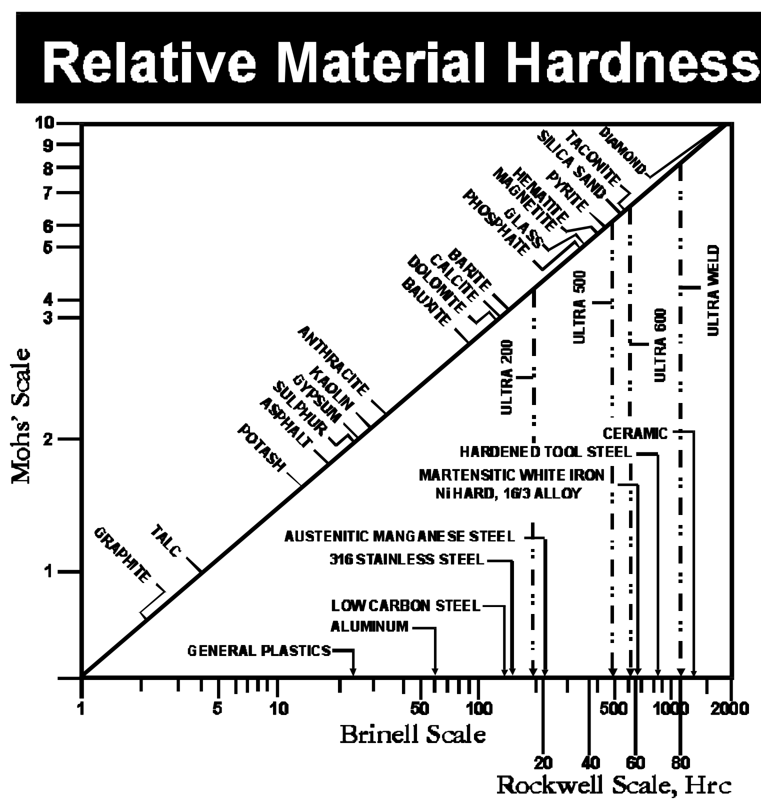
Section 2 Types of Wear

Unfortunately, the conveying of mineral products often causes the piping systems to wear. Wear is defined as the gradual and progressive loss of material due to the relative motion between the conveying medium and the pipe. There are two basic ways material is removed from the surface: the material can be dissolved through a chemical reaction, or material can be mechanically fractured from the surface.

This paper will address the mechanical interaction between the slurry particles and the piping system. Abrasive wear is produced by hard particles forced against and sliding along the wall of the pipe. The loss of material is the result of the hard, sharp angular edges producing a cutting or shearing action on the pipe wall. In abrasive erosion the loss of material is due to the relative motion between the pipe wall and a fluid containing solid particles. The magnitude of wear depends on the angle of impingement and the type of material being eroded. At close to 90 degree impingement angles (impact abrasion), the erosive wear rate is highest in brittle materials and lowest in ductile materials. In ductile materials, the repeated impinging particles plastically deform the surface to generate wear debris. With brittle materials, the impingement causes particles of material to be fractured as wear debris. Brittle materials are less wear resistant than ductile materials in an impact erosion condition. At low angles of impingement (abrasive erosion), the reverse is the case. Harder materials better resist the gouging or plowing action of abrasive particle flow.

Section 3 Hardness

Hardness can be defined as the resistance to penetration. Early methods used to measure hardness consisted of comparing a known object to an unknown. A scratch test would indicate whether one element is harder than the other. The scratch test is still utilized today in the Moh's scale (see the Relative Material Hardness chart below). The hardest material known to man is the diamond, which was assigned a value of 10. All other materials were rated relative to the diamond hardness.



Current hardness measurement technology utilizes an indenter of a specific configuration with an applied load of known value. The softer the material, the larger the diameter and the deeper the indentation. By measuring either the depth of penetration (the Rockwell Scale) or the diameter of the indentation (the Brinell Scale), the hardness of a given object can be determined. These are the two most common field measurement systems. Additionally, the Knoop or Vickers hardness system is often utilized in laboratory environments for measurement of very hard materials, such as carbides.

There is an approximate relationship between hardness and the ultimate strength of the material (see table below). As expected, for abrasive wear, the amount of wear decreases as the strength/hardness of the piping material increases. To resist abrasion, the piping system must be harder than the material being conveyed. Selecting a pipe material considerably harder than the conveyed material offers no wear advantage and typically costs more. The wear rates of various piping materials are often similar, so long as their hardness is greater than the material slurry. For instance, if the material being transported is limestone, there is no advantage in using ceramic lined pipe over an ordinary steel pipe. When the mineral is harder than the pipe, there is a very sudden and steep rise in the abrasive wear rate.

600 Brinell	**=**	**57.3 Rockwell C**	**309,000 psi Tensile Strength**
400 Brinell	**=**	**43.1 Rockwell C**	**202,000 psi Tensile Strength**
200 Brinell	**=**	**(13.8 Rockwell C**	**98,000 psi Tensile Strength**
111 Brinell	**=**	**- - - -**	**55,000 psi Tensile Strength**

Section 4 Piping Materials

Fortunately, today there are a wide variety of piping materials available to optimize system performance. These piping systems range from the simple high strength low-alloy steels to the latest in bimetallic and metallurgically bonded materials. By considering these materials with the appropriate system design parameters and piping configurations, system performance can be significantly enhanced. Material enhancements take three different approaches: 1) material alloying, 2) modifying the material microstructure (cold working, hardening, etc) or 3) composite materials.

Material Alloying

Strength and wear resistance can be improved by the addition of alloying elements to the steel during the manufacturing process. Typically the addition of higher levels of carbon and manganese increases the ultimate strength over mild steel by 70 percent, from 55,000-psi ultimate strength to the 90-100,000 psi range, and increases the as rolled hardness to 200 Brinell. This improves the wear resistance by as much as 20 %. This material is commonly referred to as AR200 piping. Both carbon and manganese are relatively inexpensive elements. Other alloying elements, such as chrome, nickel, vanadium, etc. can also be added, but at a much higher cost.

Modifying the Material Microstructure

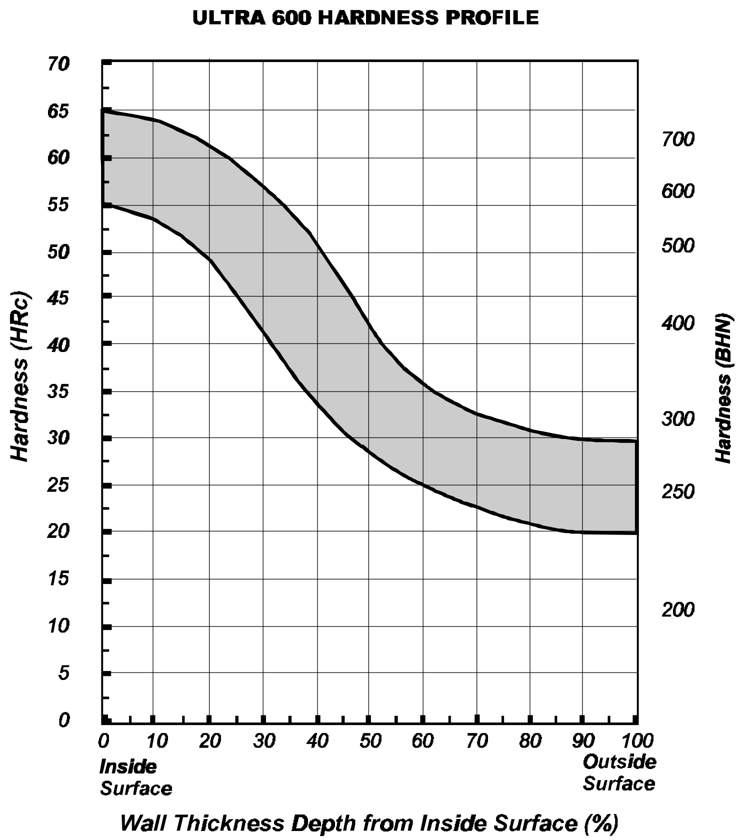
Strength and wear resistance can also be increased with secondary processing of the steel, such as cold working or heat treating. Cold working produces a stronger, tougher material, but this improvement will not match a heat-treated product. The heat treating of piping materials is accomplished either by flame or by induction hardening.

Flame hardening is a centuries old process of heating the material surface to the austenitizing temperature and rapidly quenching to produce the desired martensitic microstructure. Although flame-hardening torches, fuel gases, and quenchants have improved over the years, the application of this technology for long lengths of pipe is limited. To obtain the maximum benefit, the pipe should be quenched on the inner surface.

Induction hardening utilizes magnetic fields to induce a current in the steel pipe wall. This current rapidly changes direction, causing the heating of the product by eddy currents. The process is extremely rapid and efficient, producing only minimum surface scaling, no flue byproducts, and a very uniform material temperature.

Unfortunately, any increase in material hardness is accompanied by a loss in ductility. A product that is very hard throughout the wall thickness is extremely brittle. This brittleness is unacceptable for most material conveying systems. Piping systems are constantly flexing and moving as a result of pressure surges and spikes, as well as mechanical and physical contact at the mine site. It is imperative in all hardening processes to very accurately control the depth of hardness. This hardness profile is accomplished through material selection, quality control, and process consistency.

By utilizing a proprietary steel chemistry and by quenching the inside surface of the pipe with intensive quenching technology, an extremely hard inner surface, with a tapering hardness profile through the pipe wall thickness can be obtained.



The inner surface of the pipe can be hardened to 600 Brinell, which is sufficiently hard to withstand abrasion from most minerals. The outer surface remains ductile to accommodate normal handling during shipment, installation and maintenance practices. This type of pipe can be field cut and welded with proper procedures. The piping can be configured into a variety of traditional fittings and can accept standard end options such as flanges, weld rings, and couplings. Pipe diameters and lengths are not limited in the plant design and pipe layout, and a range of wall thickness can be hardened to provide the required service life. Induction hardened pipe can last up to 3-8 times longer than mild steel, with only a moderate price increase.

Wear Tiles and Inserts

A layer of wear tiles can also protect the inside wear surfaces of the pipes. Industrial wear tiles are made from materials that are harder and more abrasion resistant than the base steel piping. These tile materials can be cemented carbide, cast high chrome and ni-hard, aluminum oxide, and basalt. Cemented carbide tiles are usually quite small in size (about 1" (25mm) square and ¼" thick). Aluminum oxide tiles can be almost any size and have thickness over 1". Basalt is a naturally occurring igneous rock that can be molted and cast into shapes, while retaining hardness between 8 & 9 on the Moh's scale.

Wear inserts can be cast in rings and epoxied into pipe or bends. Wear tiles are adhered by cements such as epoxy or mortar. Experience has shown these products to outwear mild steel piping by a factor of 5-10 under conditions of low-stress scratching abrasion. The low-stress abrasion resistance of these hard materials to abrasion such as sand, is related to their relative hardness values.

Material	**Kg/mm^2**
Diamond	**7000-8000**
Silicon Carbide	**2300**
Aluminum oxide	**2100**
Tungsten Carbide	**2000**
Cemented carbide	**1800**
Chrome Carbide	**1600**
Basalt	**1500**
Hardened Steel	**600-850**
Mild Steel	**200**

Rubber/Poly Lined Pipe

Both a moderate hardness rubber or a poly lined (UHMW) pipe can compete with hardened and lined systems in applications of low stress, such as encountered in chutes and slurry systems having small (pea sized) minerals under low pressure. For applications of high stress, materials capable of withstanding high crushing forces are required. Depending on the particle size and shape, as well as the liner's ability to absorb the impact energy, the more ductile polymers can have a performance advantage in impact erosion applications where the angle of impingement of the slurry is at 90 degrees.

Double Wall Pipes

Modern manufacturing practices have enabled the production of pipe walls having two distinct materials. A high tensile strength outer pipe jackets a hardened inner pipe. This pipe within a pipe combination produces a slurry delivery system which features a very high abrasion resistant inner liner encased by a shock resistant outer shell. These pipes have the advantage of a very distinct and repeatable thickness of the hardness layer. The depth of the hardened layer is controlled by material selection. The final material properties are not as dependent on processing parameters, such as heating methods, temperatures, and quench characteristics.

These types of systems have two distinct disadvantages. The inner hardened layer is not bonded to the outer shell, but relies on a mechanical interference fit. Therefore, the ultimate failure of the inner liner by wear is accompanied by the liner pealing off the outer shell, resulting in a plugging obstruction. Further, the amount of remaining wall thickness cannot be measured utilizing conventional ultrasonic measuring equipment. This equipment will only measure the thickness of the outer shell, since the sonic waves are reflected at the wall interface between the inner and outer material.

BiMetallic Pipes

It is possible to produce piping products having all the advantages, but without the disadvantages of the double wall pipes. These bimetalic products rely on a metallurgical bond between two distinct chemistries. These bimetalic pipe walls can be produced through several different methods:

1) by the steel mill during the strip rolling operation,
2) added after the pipe has been formed, such as with weld overlay
3) modified by subsequent metallurgical processing.

These types of piping systems have the most advantages for wear resistance and life expectancy. The liner materials can be optimally selected for the particular slurry being conveyed, independent of the outer shell material. The outer shell is selected for pressure capacity, weldability, and field durability. Availability, size limitations, and cost are important factors in selecting bimetallic piping systems.

Section 5 System Design Considerations

The various types of piping systems have advantages and disadvantages in their application for slurry transport of abrasive materials. Several major system design considerations include: 1) Particle size, shape, and hardness, 2) Particle velocity, 3) Maximum anticipated system pressure, and 4) High wear areas (impact and flow turbulence)

Particle size, shape, and hardness

The hardness of the conveyed product is one of the major indicators of the potential for abrasive wear. For example, coal and limestone are soft materials, and are unlikely to be a problem with respect to abrasion. However, the presence of even small percentages of highly abrasive minerals will cause severe abrasive wear. As discussed previously, the system must be harder than the product conveyed to minimize abrasive wear. While small smooth particles are handled well by a durable rubber or UHMW, they can be susceptible to wear from sharp or jagged materials.

Particle Velocity

Of all the variables which influence the wear rate of piping products, velocity is the most important. The rate of wear is exponential with regard to velocity. Doubling the velocity will increase the wear rate by 4 – 6 times, depending upon the system arrangement. Decreasing the velocity may cause separation and segregation of the material in the slurry pipe.

The flow of slurries through a pipe is complex. The flow characteristics depend upon particle size and shape, distribution, velocity, etc. Slurries are categorized as either nonsettling or settling. Non-settling slurries flowing in a pipe have a uniform distribution of particles across the flow section. Settling slurries flowing in a pipe normally flow as a mixture in which a portion of the solid particles are carried as suspended load and the reminder are moved as bed load. As the velocity is decreased, a greater portion of solid particles are carried as bed load. Settling slurry characteristics will vary significantly due to the increase in frictional resistance of the solid particles sliding, rolling and bouncing along the lower portion of the pipe. If the velocity is decreased further, a stationary deposit forms in the bottom of the pipe. Naturally graded minerals and ores consist of a spectrum of particle sizes, and deposits begin to occur at the velocity coincident with that of the most easily deposited sizes. When accurate values of head

Technologies

When abrasion-resistant piping is required, several alternatives are available. Each possess unique characteristics. Each has it's advantages and disadvantages. Proper selection requires insight into the piping system including detail, objectives and constraints.

Attributes, advantages and disadvantages of several alternatives are illustrated below.

	MILD STEEL	FIBERGLASS PLASTIC	"AS-RUN" PIPE	INDUCTION HARDENED PIPE	WELD OVERLAY	CAST / LINED PIPE
HARDNESS	120 - 150 BHN	N/A	180 - 220 BHN	480 - 650 BHN	> 600 BHN	300 - 700 BHN
ABRASION RESISTANT	POOR	Can be impregnated with abrasion resistant "beads"	Moderate	Very Good	Excellent	Excellent
IMPACT RESISTANT	Good	Good	Moderate	Low Marginal	Low Moderate	Poor
STRENGTH	Good	Poor can crush	Moderate	Excellent	Good	Excellent
SIZES	Unlimited	Limited	100'	50'	Limited to 50'	18'
HANDLING & INSTALLATION	Excellent	Excellent	Excellent	Very Good	Very Good	Very Heavy Very Brittle
FABRICATION	Unlimited	Limited (special equip.)	Unlimited	Some limitations	Some limitations	Very Limited (to patterns)
WEAR MONITORED	Readily with Ultrasonic	No	Readily with Ultrasonic	Readily with Ultrasonic	No	No
EMERGENCY REPAIR	Easily completed	Limited (special equip.)	Easily completed	Easily Patched	Easily Patched	No
INITIAL COST		Less than Mild Steel	10-25% above Mild Steel	50-100% above Mild Steel	4 - 5 times Mild Steel	3 - 6 times Mild Steel
LIFE EXPECTANCY		2-4 times Mild Steel	1.5 - 2 times Mild Steel	3 - 8 times Mild Steel	6 - 20 times Mild Steel	10 - 20 times Mild Steel
ADVANTAGES	Low cost Readily available	Lightweight Corrosion resistant Lengths to 100'	Improvement In wear over mild steel Lengths to 100'	Excellent combination of abrasion & impact resistant	Excellent for abrasion wear	Excellent for abrasion wear
DISADVANTAGES	Poor abrasion resistance; Costly change-out	Difficult repairs, Thermal movement	Limited in wear, No corrosion resistance	No corrosion resistance, Low ductility	Limited length and diameter	Very heavy; supports req'd Very Brittle Costly

loss, minimum transport velocity, and other data are required, actual pipe-flow testing should be performed under controlled conditions.

Maximum Anticipated Pressure

The system must be designed to withstand the maximum hydraulic and mechanical loads imposed. Couplings, flanges, hoses, and valves must be adequate for the intended service. The pipe wall thickness must have sufficient strength to withstand the maximum pressure during the service life of the system. Since mineral slurries can be very abrasive, the pipe system must have sufficient wall thickness to withstand the maximum pressure after a significant amount of wear has occurred. Heat treating improves the tensile strength of the steel, and these types of piping systems can be utilized to a thinner wall before replacement is necessary.

The minimum wall thickness for standard piping systems can be readily determined from available charts, or calculated from the following formula. An additional factor of safety may be required, based upon the application requirements (see ANSI/ASME B31.11)

$$t = \frac{Pi * D}{2S}$$

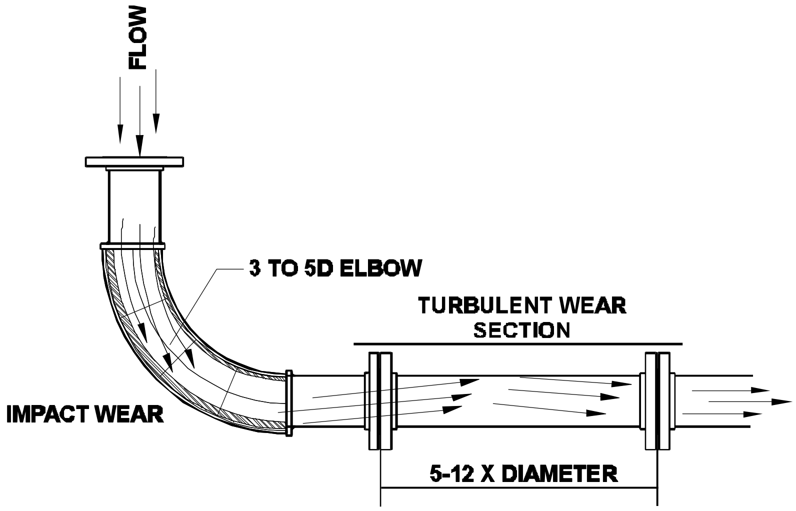
t = pressure design wall thickness (inches)
Pi = internal design pressure (psi)
D = nominal outside diameter (inches)
S = applicable allowable stress value (psi)

High Wear Areas

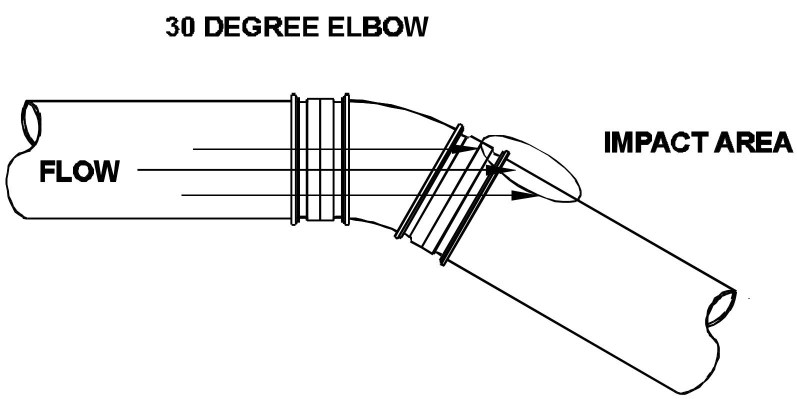
As discussed above, there are distinct types of wear experienced in a typical piping system. The straight sections most commonly experience abrasive, or scratching wear. Size transitions and directional changes experience both abrasive and impact wear and must be designed differently. Ideally, the entire system would be designed with consideration for the appropriate wear mechanism.

Wear at the bends or elbows often provide maintenance and operational problems. Many times, frequent replacement, repair, and the associated expense is accepted as the norm. However, by designing the bends to withstand the wear mechanism and reduced operating costs can be realized in the system.

Solutions to reduce wear at the bends and elbows include longer radius bends, induction hardening of the bends, installing wear backs, and lining the bend with various abrasion resistant materials. Often these solutions utilize specialty materials, designed specifically for high impact wear areas. The outlet pipes (tangents) of these elbows must also be made from special materials due to the transitional flow turbulence occurring after the elbow.



Elbows less than 45 degrees often create special wear problems on the straight pipe sections after the elbow outlet. Since the material flow can proceed basically unimpeded through the bend, impact occurs directly on the outlet piping (see illustration). Again, by utilizing more abrasion resistant materials in these locations, more uniform life and wear characteristics can be achieved.

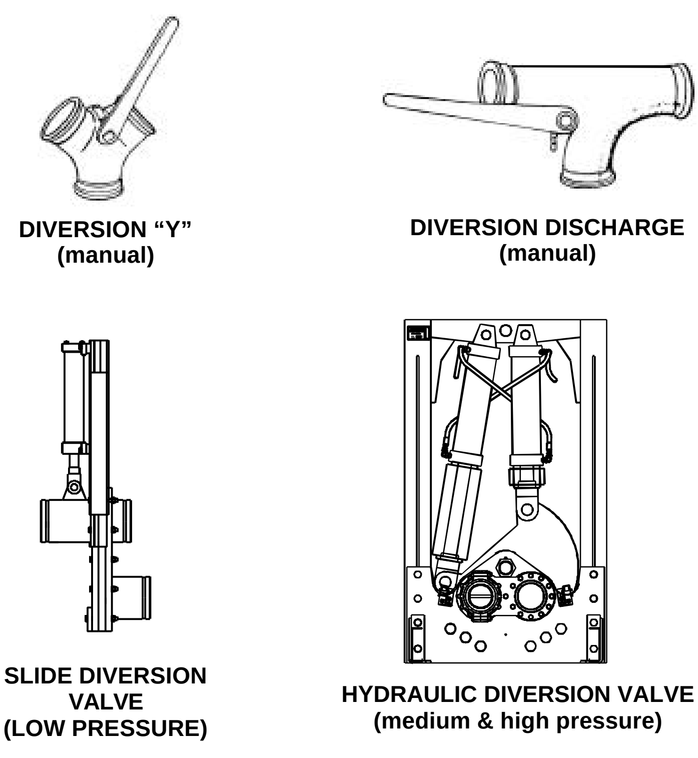


Section 6 Accessories

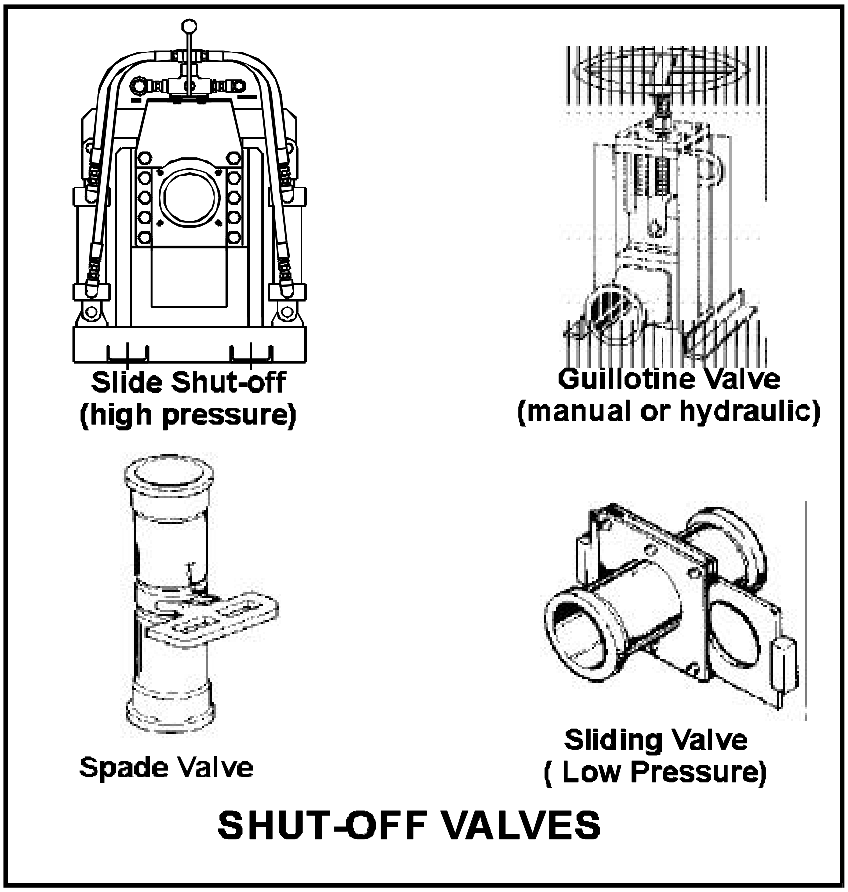
The proper selection of piping components and accessories will ultimately determine the piping system life expectancy, as well as the operation and maintenance characteristics of the slurry transport system.

Valves

Various types of valves are available to shut off or to divert the slurry flow. These valves include ball valves, directional valves, and guillotine type valves. Consideration must be given to the system design pressure, particle size, and flow velocities. Typically slurry system pressures can be classified as low (<500 psi), medium (<1500 psi) or high (>1500 psi). The following illustrations show various valve configurations successfully utilized in slurry transportation, as well as high pressure paste back fill applications.



DIVERSION VALVES



Couplings

The system piping components can be joined utilizing either traditional ANSI bolted flanges, or with various types of specialty coupling clamps. These clamps include quick release snap-type as well as bolted type. The bolted type connections are less costly, able to withstand higher pressures, and are less susceptible to accidental release. Quick release type clamps are utilized in areas that require rapid and frequent removal and disassembly. Raised end type coupling systems can be designed to withstand operating pressures in excess of 2000 psi.

Section 7 Successful Applications

PASTE` BACKFILLING OF MINES

A number of mines are installing paste fill systems to replace the current sand fill method. The justification and economies of this conversion include: higher production levels (less wait for dewatering), increased grade of ore to the mill, decrease of stope ore left as pillars, improved haulage with the removal of excess moisture, increased filling rates, and a higher strength fill with less waiting time.

The unique problems associated with paste fill applications range from extremely rapid system wear to paste separation and system blockage. Attempting to unblock several thousand feet of vertical pipeline is both dangerous and expensive. The cost to replace a prematurely worn drop shaft exceeds millions of dollars.

One successful solution is to maintain the vertical line full of paste. This prevents the rapid wear and tremendous impact loads caused by “air mailing” the paste fill. It also eliminates the partially full line and the accompanying air pockets which cause pipeline hammer and rapid surges in material velocity. Maintaining a full line of paste also prevents the separation and segregation which occurs as result of the free falling paste. To maintain a full line requires special operating procedures, as well as specialized high pressure system and accessories designed specifically for these applications.

STARTUP

The system valve at the base of the vertical pipe is closed and the entire pipe is filled with water. A plug/ball is inserted into the pipe above the water. Sufficient priming slurry to lubricate the line is added above the plug. A special bleed water valve at the base is opened to allow a controlled descent of the lubrication slurry, followed by the paste fill. The paste fill hopper and line must remain full at all times. The start-up water discharged from the line is pumped back to surface.

Once the start-up water has been discharged from the system, the system shut-off valve is opened. This allows the paste fill to flow by gravity thru the remaining piping system to the stopes. The level of the paste in the hopper must be closely monitored to ensure the hopper level does not drop below a set minimum level. If the level drops due to inadequate batch plant supply or mix design, the system valve modulates to maintain the appropriate paste level. Control of the paste fill slump by the batch plant is extremely critical to successfully balancing the paste fill system.

CLEAN-OUT

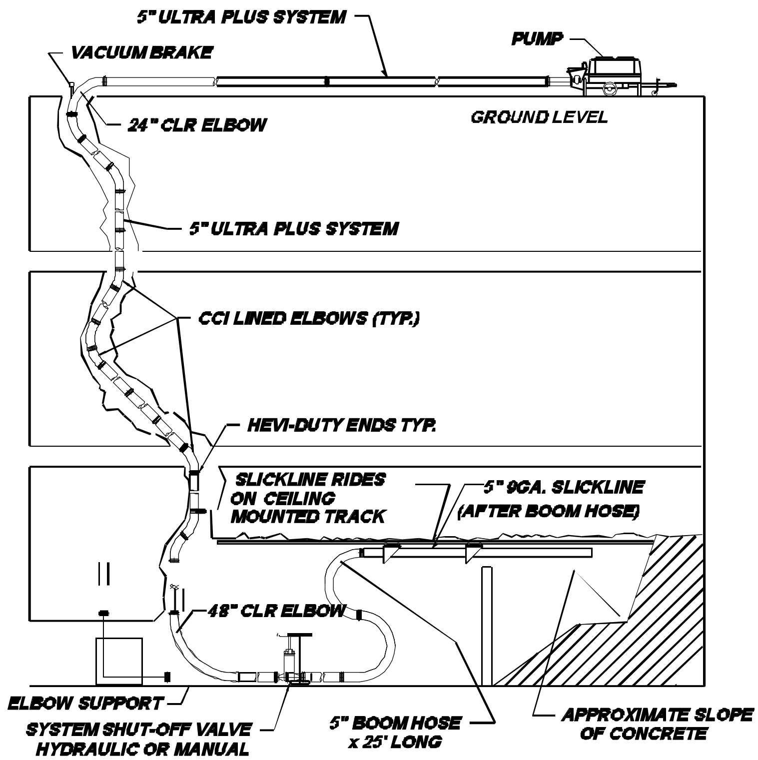
Paste fill operations typically operate 24 hours per day after startup. To shut down and clean-out the paste fill line, a clean-out ball is inserted into the pipe above the paste fill. This ball scrubs the pipe wall while preventing the mixing of the water with the paste. A minimal amount of water is then pumped above the ball to aid in cleaning. The system shut-off valve is opened, and the paste fill pulls the ball and water through the system. The amount of water utilized is considerably less than attempting to water flush the entire line.

EQUIPMENT

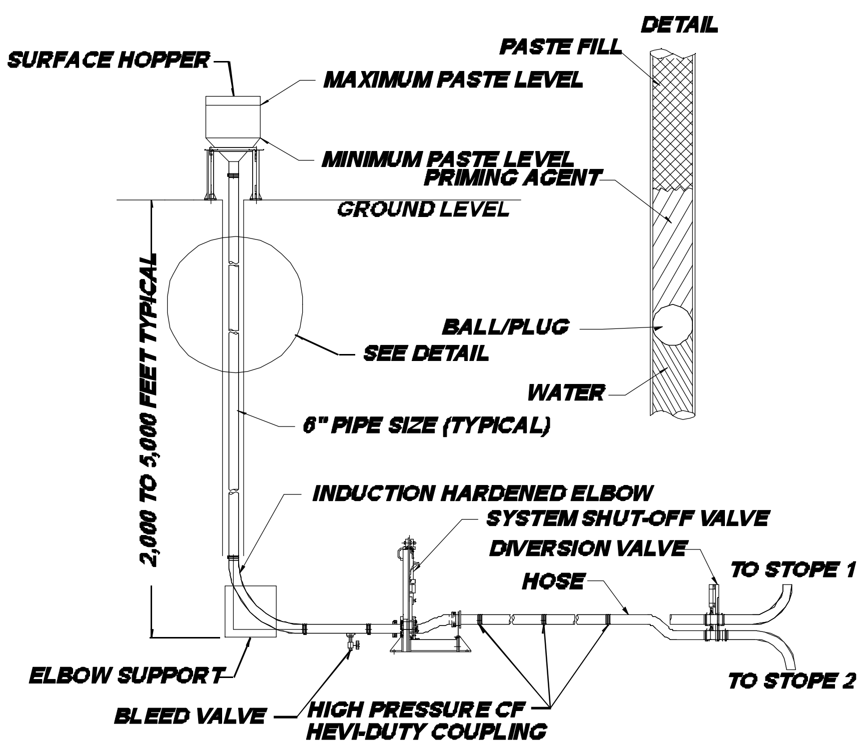
While basic in concept, paste fill applications require a number of components and accessories designed specifically for this type of service. The pressures encountered can be extremely high (in excess of 4000 psi) while the material conveyed is extremely abrasive. Leakage at these pressures causes water jet cutting of the components, resulting in rapid system failure and potential system blockage.

The system valve is a specially designed shut off valve utilizing one inlet and two outlet ports. The valve is constructed from abrasion resistant high strength steel plates. Hardened floating rings seal the openings under pressure. A massive, high-strength pivot bolt and nut combined with a special thrust bearing withstand the thrust loading exerted on the plates by the high pressures. A unique swivel coupling and gasket allows the inlet pipe to rotate between the two outlet ports at these high pressures.

All of the system components must be appropriate for the flow and pressure. The base elbow and adjacent piping must be adequately supported and restrained to withstand the loading. Induction hardened elbows and piping joined with raised end “Hevi-Duty” couplings are utilized throughout the 6” system. Original layout designs called for 8” piping to be utilized for the paste fill. Experience has shown that 6” system will flow in excess of 120 tons/hour of paste fill at the 4000 foot level, with paste fill of 7-7 1/2” slump. The original 8” system produced excessive velocity and was prone to separation and blockage.



Pumping Paste Backfill



Gravity Paste Backfill

CONCLUSION

Construction Forms is the world leader in the design and manufacture of high pressure piping systems and accessories for concrete distribution. The CF Ultra Tech division is a leader in abrasion resistant piping system technology for mining, pulp & paper, coal fired boilers, etc. Utilizing the unique products and experience of these two divisions provides the technology required to solve the problems encountered in mining applications.

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