FORMING

LUBRICATION OF STEEL SHEET AND STRIP FOR FORMING

TECHNICAL BULLETIN TB-F1

Rev 2, November 2003
This issue supersedes all previous issues

1 THE NEED FOR LUBRICANTS

When forming steel sheet, a lubricant is used to enable the workpiece to slide over the die, roll or tool surface under controlled or reduced friction conditions. As some form of lubrication is essential to most deep drawing operations and useful in many others, it must be considered to be a primary factor in the process. For this reason, close attention must be given to lubrication when forming. Important benefits gained from the use of lubricants are that the blank or strip can be formed with minimum surface marking and is able to form a panel shape with more uniform stretch over a punch, or with minimum friction as the metal moves around die or roll radii. Lubricants can range from simple forms such as residual mill or rust preventative oils normally applied by the steel sheet manufacturer, to complex formulations with many components. With judicious choice of lubricant some cost savings can be achieved in materials and product design.

The use of a suitable lubricant is only one of many factors affecting the performance of a blank in a pressing operation. The surface of the blank and dies, together with punch-to-die clearances and other factors discussed in this bulletin need to be carefully considered. Smooth tools do not necessarily give the best press result, nor the thickest oil the best lubrication.

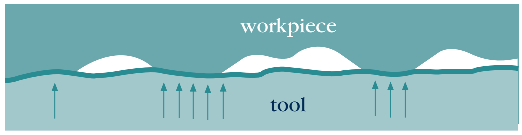
This technical bulletin relates primarily to press forming operations using uncoated low carbon steel sheet. The same principles of lubrication can also be applied to the other operations *(bending, spinning, roll-forming, punching)* and other sheet materials including metallic-coated and organic pre-painted steels.

2 SURFACE CHARACTERISTICS

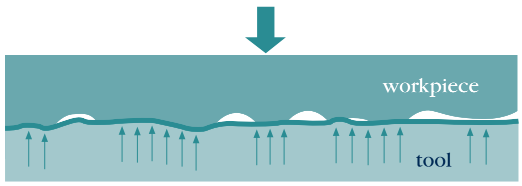
Surfaces in contact actually touch at relatively few points. These areas of contact are influenced by the sheet flatness and then, in the areas where the surfaces coincide, by surface finish or height and density of peaks protruding above the average surface level for both the sheet and tool. Under light loading conditions with no lubrication these peaks will be relatively undeformed and the theoretical contact surface will be small *(Figure 1a)*.

When loading is increased the high points flatten, increasing the contact area *(Figure 1b)*. As this loading progresses further flattening occurs *(Figure 1c)* and welding of the two surfaces may result from the heat generated by the movement induced by shear loading coupled with increased friction from the larger area of contact. Lubrication during forming is used to prevent contact of sheet and tool surfaces or to control the degree of contact and eliminate welding.

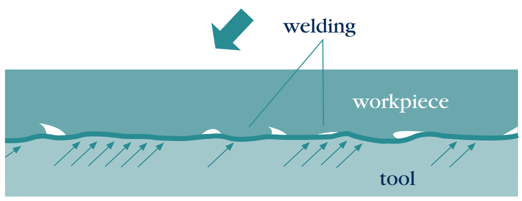
Figure 1 – Surface Characteristics Under Load



(a) Light normal loading of unlubricated surfaces



(b) Heavier normal loading with asperity flattening



(c) Normal and shear loading leading to further flattening distortion, and welding with tearing

3 LUBRICATION MODES

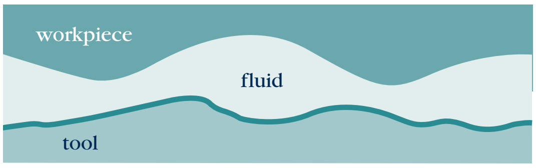
There are three main lubrication modes; hydrodynamic *(fluid film)*, boundary *(surface conditioning by chemical absorption)* and solid film *(physical separation using low friction solids)*. Fluid lubrication implies the separation of the surfaces by a continuous film of lubricant so that even the high spots of the two surfaces are well separated *(Figure 2a)*.

BLUESCOPE STEEL

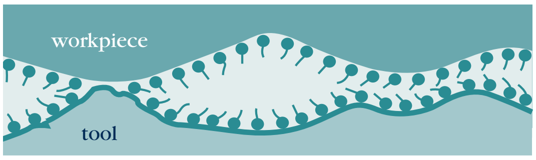
In boundary lubrication the lubricant film is too thin to allow complete surface separation but a chemically bonded constituent, as illustrated in Figure 2b, assists in preventing pickup and welding as additional contact is made during the press operation.

Extreme pressure *(EP)* lubricants aid boundary lubrication by generating chemically bonded layers on the two surfaces, inhibiting the welding of the peak contact areas *(Figure 2c)*.

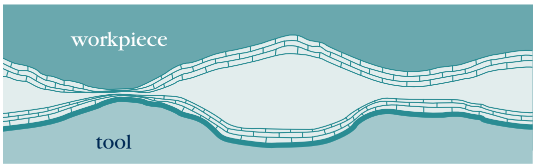
Figure 2 – Lubrication modes



(a) Fluid (hydrodynamic) lubrication



(b) Boundary lubrication with an oilness agent



(c) Extreme pressure boundary lubrication with a pigment (mechanical EP agent)

3.1 Fluid Lubrication

Fluid lubrication occurs where the metal surfaces are separated by a continuous fluid film of lubricant which is considerably thicker than the heights of the metal surface irregularities and with sufficient viscosity to prevent sideways leakage. Thus the press force is entirely supported by the lubricant film.

The friction restraining the flow of the blank into the die is then dependant on the shear strength of the lubricant. Thus metal movement can only be controlled by changing lubricant properties and not by changing blankholder pressure. Therefore, fluid lubrication is not suitable for pressing where variable blankholder pressure occurs. Furthermore it is difficult to prevent leakage from between the two surfaces.

Fluid lubricants range from low viscosity high flash solvents such as HF Kerosene, low viscosity mineral distillates such as base lubricating oils, PAO *(poly alpha olefins)* polybutene, polyethylene glycol and vegetable and animal derived oils, esters and fats. These fluids can range in viscosity from that of water through to thixotropes *(near solids)*.

3.2 Boundary Lubrication

Boundary lubricants are those that react chemically with the workpiece and the tool surfaces. This is evident by the use of fatty acids or esters of fatty acids. These have a polar attraction to metal surfaces and in so doing, change the frictional characteristics of the two mating surfaces. Friction co-efficient can be modified dramatically by this process. There are a great variety of boundary lubricants available to the forming lubricants blender and each has a predictable range of usefulness, usually related to operational temperatures and pressures encountered between tooling and job.

"Extreme pressure" lubricants are on the more chemically reactive end of the scale of boundary lubricants and these are mostly derived from sulphur and chlorine. Chlorinated paraffin was commonly used as a reactive extreme pressure agent in heavy drawing operations on steel sheet, but, its use has diminished because of environmental pressures and the corrosion it can cause. Great advances have been made in the use of sulphur and in developing sulphur compounds with a controlled range of reactivity and corrosion potential.

Mixtures of boundary lubricants are often used to enhance performance by synergism. Combinations of fatty esters, sulphur and phosphate ester compounds can provide a scale of controlled activity to fluids used in forming lubricants and provide lubrication to cover a wide scale of working temperatures and pressures. The correct selection of boundary lubricants in a forming oil formulation, will allow higher than usual passing speeds, the long term protection to expensive tooling, enhancement of the surface finish of formed components and their protection from corrosion in storage.

3.3 Solid Film Lubrication

Apart from the obvious examples of these lubrication types i.e.. graphite, mica, molybdenum disulphide, magnesium silicate *(talc)* and PTFE *(polytetrafluoroethylene)* there are a number of new compounds, which are solids, available to the lubricants blender and these include lithium, zinc and calcium stearates and other solidified combinations of boundary lubricants. All these can be used as a solid film attached to sheet feed by themselves or, used suspended electrically within fluids and used as a combination of solid film and liquid film lubrication. They can be sprayable fluids which contain a high proportion of boundary additives and sub-micron sized solids which act together to protect tooling from galling and cold welding, and to protect the job during and after its deformation.

BLUESCOPE STEEL

4 LUBRICANT FUNCTIONS

A major consideration in selecting a lubricant for a particular operation is defining the major functions required in that operation. The lubricant can be required to contribute to some and at times possibly to all of the following aspects during the metal forming operation:

- control of friction
- tool wear
- control of temperature
- workpiece surface preparation

4.1 Control of Friction

Frictionless lubrication can be obtained by fluid type lubricants with changes to viscosity and tackiness used to control blank flow. This is an impractical way to control metal flow and for these conditions a boundary type lubricant is used with increased holddown pressure being transmitted to the blank. Under these conditions the sheet metal surface is smoothed by flattening of the high spots. As a result the actual contact surface is increased and contact pressure decreased.

The ability of the lubricant to reform on these new surfaces to reduce friction is important, and is an advantage of the chemically bonded boundary lubricants.

Selective lubrication is sometimes necessary when pressing panels where severe stretching takes place in some areas and, say, drawing in other areas, such as might be encountered in an auto skin panel. Lubrication requirements can vary for different areas. These requirements are customarily met by manual application of lubricant in selected areas of the workpiece. Such application methods tend to be expensive but design commitment may make the technique the only practical means of achieving a desired result.

Phosphate type chemical conversion coatings are another form of selective lubrication. These can be used in conjunction with chlorinated or sulphochlorinated lubricants to provide an effective, impervious EP barrier between surfaces. These are aimed at uncoated steels. Difficulties may be incurred if used on metallic coated products that subsequently undergo powder coating.

4.2 Tool Wear

Fluid type lubricants, by separating the blank and die, prevent tool wear but at the same time prevent frictional control of the draw.

In boundary lubrication this metal to metal contact is used to control flow but at the expense of die wear. The rate of wear will depend on the die materials as well as the lubricant.

With extreme conditions of pressure and temperature, welding will occur between metal high spots, resulting in pick-up on either the blank or die surface. This pick-up will rapidly cause damage to both die and workpiece and so the lubricant needs to be carefully selected to prevent or at least reduce this problem.

4.3 Control of Temperature

It is obvious that by decreasing friction the heat generated in the pressing will be reduced. The temperature can also be reduced by applying a greater volume of lubricant or with water which absorbs a much larger portion of heat than mineral oil. An oil in water emulsion may be considered an advantage.

4.4 Workpiece Surface Protection

It is desirable for a lubricant to provide protection against atmospheric corrosion following pressing, especially when parts are stored for extended periods. Some lubricants with high chlorine or sulphur content, or water emulsions, provide generally poor protection. Soaps or waxes provide the best protection.

5 LUBRICANT CONSIDERATIONS

5.1 Lubricant Stability, Handling & Storage

Some lubricants have limited stability or shelf life. They will break down under certain conditions by bacterial action, or simply separate on standing. Emulsifiers are added to mineral oils, fatty oils and waxes to allow formation of stable emulsions. Deterioration with age also occurs after forming a part in some instances and subsequent removal may be difficult. This aspect must be examined before a decision is made to use a particular lubricant. All OH&S issues must also be considered prior to selection.

Skin Irritation

Contact with oil or lubricants can cause skin irritation to certain people. Appropriate protective clothing or barrier creams should be used when handling such compounds. Material Safety Data Sheets *(MSDS)* should be supplied with lubricants and instructions for handling these should be followed. In the event of contact with skin, removal should be done in accordance with the MSDS instructions.

Flammability

Where applicable, precautions should be taken to eliminate fire hazards by such means as good housekeeping and storage of materials under approved conditions.

5.2 Lubricant Application and Removal

In many instances lubricants have to be removed prior to further processing, therefore not only their application but also their removal must be easy.

The least expensive method of application is by spray or roller coating just prior to pressing. As far as removal is concerned, the choice is between solvent degreasing or the use of alkali cleaners. Table 1 provides information on the suitability of water-based cleaners and degreasers or solvents for removing the various types of lubricants.

Solvent degreasing presents many problems, such as effluent disposal, and the alkali cleaning method is preferred provided facilities are available to treat the oil-contaminated cleaning solution.

Safe, non-toxic characteristics are also required for cleaners. Solvent cleaners must be used with the correct equipment and ventilation. For example, hydrocarbon solvents are relatively non-toxic but are flammable, while non-flammable solvents, such as the chlorinated hydrocarbons, are often toxic by inhalation or by skin absorption.

Further detail for cleaning of metal panels is contained in Australian Standard 1627, Part 1, 1989 Preparation and pretreatment of surfaces – Cleaning using liquid solvents and alkaline solutions.

Note that there are a wide range of contaminants that can find their way into a recirculating lubricant system and the filtration system has to be up to the job. Most solid contaminants can be removed via a variety of filtering methods including centrifugal, magnetic and paper. Miscible fluids on the other hand are not easily removed. For example, mill oil can contaminate the oil in a wash oiler, resulting in the possible dilution of active constituents in the wash oil.

5.3 Post-Forming Operations

Possible problems with subsequent operations such as spot welding, the inability to phosphate without careful cleaning, or the deleterious effects of some additives on paint systems, should be carefully considered when selecting a lubricant. Sulphonated lubricants will interfere in vitreous enamelling operations.

6 TYPES OF LUBRICANTS

Basically, the types of lubricants used with steel sheet are:

- mineral oils
- straight fatty oils
- undiluted EP oils
- soap solutions
- soap-fat compound emulsions
- phosphate coatings
- dry film coatings
- solid lubricants

6.1 Mineral Oils

These are not very effective lubricants. Used straight, mineral oils are dependent on the maintenance of a fluid layer between the die and the workpiece. Provided viscosity is not high, application is relatively easy and the oils can be readily removed by detergent cleaners or, if preferred, solvent type cleaners.

6.2 Soluble Oils

Soluble oils are an emulsion of mineral oil in water, used for moderate forming operations. Boundary and EP additives can be added for more extreme applications.

6.3 Straight Fatty Oils

These are oils such as lard and palm oil, and although very efficient lubricants, are relatively expensive. The oils are used with a solvent as with the combination of lard and kerosene.

6.4 Undiluted EP Oils

These types are mineral oils plus EP additives containing elements such as chlorine, sulphur, nitrogen and phosphorus which form iron chlorides, sulphides, nitrides and phosphides on the workpiece and tool surface.

6.5 Soap Solutions

Soap solutions are generally potassium or sodium stearates or oleates diluted with water. Soap concentration is increased with severity of the drawing operation. These solutions, good for high speed lubrication requiring heat dissipation, can be readily applied and are removed by water-based cleaners.

6.6 Soap-Fat Compound Emulsion

These are fairly thick pastes containing between 35% and 40% fats and are diluted with water, depending on the severity of the operation. Solid fillers can be added for severe applications. Application is easy but removal is difficult in either water-based or solvent cleaners.

6.7 Phosphate Coatings

Phosphate coatings provide a barrier completely separating the workpiece and tools, and coatings remain intact even in the most severe applications. At times, a soap is used with this coating as a lubricant. The phosphate crystal structure, by providing a series of reservoirs containing the lubricant, reduces the frictional force on the blank surface allowing improved blank flow. This type of coating is advantageous when attempting to press parts where maximum performance from the blank material is required in the forming operation.

BLUESCOPE STEEL

Table 1 – Lubricants commonly used in press forming uncoated low carbon steel sheet

Press Operation Severity*	Type or composition of lubricant	Ease of removal by		Protection against rusting
		Water-based cleaners	Degreasers or solvents	
WATER-BASED LUBRICANTS				
Low	Water emulsion of 5 to 20% general purpose soluble oil or wax	Very good	Good	Fair
Moderate	Water solution 5 to 20% soap	Very good	Very good	Fair
	Water emulsion of heavy duty soluble oil (contains sulphurised or chlorinated additives)	Very good	Good	Fair
High	Soap-fat paste, diluted with water (may contain wax)	Fair	Poor	Fair
	Water emulsion of heavy duty soluble oil (contains a high concentration of sulphurised or chlorinated additives)	Very good	Good	Fair to poor
Maximum	Pigmented soap-fat paste, diluted with water	Poor	Very poor	Good
	Dry soap or wax, applied from water solution or dispersion (may contain soluble filler such as borax)	Good	Very poor	Good
OIL-BASED LUBRICANTS				
Low	Mill oil, residual (usually about 20mm²/s at 40°C)	Good	Very good	Fair
	Mineral oil (5 to 65mm²/s at 40°C)	Good	Very good	Fair
	Evaporating oil (eg SHELLSOL T)	Removal not required		Nil
Moderate	Mineral oil (20 to 65mm²/s at 40°C) plus 10 to 30% fatty oil	Good	Very good	Fair
	Mineral oil plus 2 to 20% sulphurised or chlorinated oil (EP oil)	Good to fair	Good	Fair to poor
High	Fatty oil	Fair	Fair	Fair
	Mineral oil (20 to 65mm²/s at 40°C) plus 5 to 50% of: (a) Non-emulsifiable chlorinated oil	Poor	Good	Very poor
	(b) Emulsifiable chlorinated oil	Good	Good	Very poor
	Concentrated phosphated oil	Fair	Fair	Fair
Maximum	Blend of pigmented soap-fat paste with mineral oil	Poor	Poor	Fair
	Concentrated sulphochlorinated oil (may contain some fatty oil) (a) Non-emulsifiable	Very poor	Fair	Very poor
	(b) Emulsifiable	Good	Fair	Very poor
	Concentrated chlorinated oil: (a) Non-emulsifiable	Very poor	Fair	Very poor
	(b) Emulsifiable	Good	Fair	Very poor

*** Refer to Table 2 for press operation severity detail**

American Society for Metals information

BLUESCOPE STEEL

6.8 Dry Film Coatings

There are essentially two types of dry film coatings, solid soap and plastic polymer. Soap-based films can be continuously applied to strip, removing the water constituent in warm air. Film thickness can be controlled within narrow limits. Lubricants such as Kold Lube are basically soap films constituted to form a hard, high melting point layer which, on melting, provides both fluid and boundary lubrication. Plastic polymer films are deposited from warm trichloroethylene solution and are acrylic resins of varying molecular mass. If sufficiently thick, these plastic films will provide fluid lubrication conditions which change to pressure sensitive boundary conditions as the thickness is decreased.

Polyethylene film (*CORSTRIP®*), applied to COLORBOND® prepainted steel strip or placed loosely over blanks in a press, provides excellent dry film lubrication.

6.9 Solid Lubricants

Graphite and molybdenum disulphide are two solid lubricants used separately or as additives for other lubricant systems. Other solids *(which act to increase friction)* are clay, talc and chalk. These solid lubricants are basically used to separate or protect sliding surfaces from damage under extreme pressure, but may be used to increase or decrease the frictional resistance depending on the crystal structure of the solid. Removal is often difficult when combined with soap-fat pastes.

6.10 Coatings on Steel Sheet Products

Most of the coatings on steel products *(zinc, zinc/aluminium, painted finishes)* themselves act as solid lubricants and are sufficient for some forming operations. The effectiveness of the coating in this way should be tried before additional lubricants are considered.

7 SELECTION OF A LUBRICANT

While simple pressings are not dependent on the lubricant, increasingly difficult pressings will need more critical selection and indeed may require blending of mineral oil with both polar type additives and EP additives. The reason for balancing the formulations is that polar additives are more effective than EP agents in reducing friction, while EP agents are better able to produce and maintain a boundary film between tool and workpiece under conditions of severe deformation. Viscosity and tackiness can be as important as chemical composition especially during the early stages of the drawing process. The formulation of the lubricant can become very involved and is frequently determined on an experimental basis.

Tables 1 and 2 provide a basis for identifying the severity of an operation and indicate the type of lubricant which should be suitable. A better lubricant can often compensate for problems arising from product design, tool geometry or variations in properties in the workpiece.

7.1 Drawing

Determining the best lubricant for a particular draw is not generally a clear cut decision, but Tables 1 & 2 provide some guidance.

Naturally, less effective and cheaper lubricants than that recommended may work, but for continued satisfactory pressing under the normal range of press operation and material variations, it is recommended that the nominated lubricant be used.

Table 2 – Severity ratings of forming operations

LOW SEVERITY

1. Drawing a cup with 10% reduction in diameter.
2. Forming with a maximum localised stretch of 10% in a 25 mm length.
3. Bending 90° around a radius equal to the blank thickness with a flange equal to, or greater than, 25 times the blank thickness.
4. Blanking and piercing sheet up to 2.5 mm thick with clearances of 10% of sheet thickness.

MODERATE SEVERITY

1. Drawing a cylindrical shell with 20% reduction in diameter.
2. Forming with a maximum localised stretch of 20% in a 25 mm length.
3. 90° bend around a radius less than the blank thickness with a flange width of 15 times the blank thickness.
4. Blanking and piercing sheet thicker than 2.5 mm.

HIGH SEVERITY

1. Drawing a cylindrical shell with 30% reduction in diameter.
2. Forming with maximum localised stretch of 30% in a 25 mm diameter.
3. Bending sheet less than 3 mm thick 90° with a flange width of equal to, or less than, 10 times the blank thickness.

MAXIMUM SEVERITY

1. Deep drawing a cylindrical shell with 40% or greater reduction in diameter.
2. Forming with localised stretch of about 40% in a 25 mm length.

BLUESCOPE STEEL

7.2 Roll-Forming

Although lubrication increases roll-forming efficiency it is not always necessary. In roll-forming the need for any type of lubricant depends on the surface of the steel strip to be processed and coating type, roll former speed, roll material, roll condition and severity of forming. Table 3 lists the principal surface types available and suggests the lubricant characteristics required.

7.3 Bending and Spinning

7.3.1 BENDING

A lubricant is not usually required for simple bending. If it is, mill oil or light mineral oil will usually suffice. For COLORBOND® pre-painted steel blanks, use only SHELLSOL T or similar evaporating oil formulations.

7.3.2 SPINNING

Manual spinning should not require lubrication as heat and friction can be closely controlled by use of special tools such as roller heads. If lubrication is required, mill oil or light mineral oil will usually suffice.

COLORBOND® pre-painted steel blanks would not normally require a lubricant. The organic coatings have sufficient lubricity in themselves for the process. If a lubricant is used, the rotational and applied tool force could cause lubricant degradation, risking permanent staining of the blank surface.

Power spinning is limited to materials able to withstand the severity of the process. Because of the localised high temperatures generated, a water-based fluid is usually used to flood the workpiece and tools during spinning.

7.4 Punching Electrical Steels

Punching oil is not usually required for electrical steels coated with the organic insulation CP3. The coating acts as a lubricant, significantly reducing the rate of tool wear, particularly on tool faces. Where slot configurations are difficult, or where sharp corners cause inefficient stripping and consequent side wear on the punch, the use of a punching oil is beneficial.

Table 3 – Guide to roll-forming lubricant requirements for various sheet steels

Steel surface	Lubricant
Hot-rolled with scale	Penetration, wetting & flushing are essential, usually soluble oils with proper balance of EP additives & wetting agents.
Hot-rolled, pickled	Soluble or light oils with good wetting. Rust preventative oils help.
Cold-rolled	Heavy duty EP type water solubles, oils with EP additives & good wetting. Minimum drag out helps.
ZINCALUME® GALVALUME® ZINCANNEAL® & ZINCSEAL®	Light oils, evaporating compounds, specially formulated solubles, if coating itself is not sufficient. Note that the resin coating on ZINCALUME® steel may be sufficient for the forming operation and in cases such as roll forming the use of a lubricant may cause slippage.
COLORBOND® pre-painted steel	SHELLSOL T or similar formulations, if coating itself is not sufficient.

8 COMPARISON OF LUBRICANTS

Although the effect of a lubricant on improving the drawability of a blank can be estimated using techniques such as grid strain analysis *(see Technical Bulletin TB-F7)*, the effectiveness of the lubricant to reduce tool wear can only be determined ultimately by a long press run.

When deciding which lubricant to use, a review of the constituents which might be added to reduce tool wear for a severe operation will probably indicate that one lubricant will be more satisfactory than another. Information should be obtained from lubricant manufacturers or suppliers.

Evaluation of a new lubricating system is not meaningful unless application equipment and recirculating systems have been carefully cleaned beforehand. Flushing with the cleaning agents and the new lubricants will be necessary to clean out scale and other accumulated debris, and to remove all previous lubricant.

Mixing of lubricants or application of one lubricant over pre-existing lubricants can often result in performance poorer than either lubricant alone.

Laboratory tests for the evaluation of lubricants, even those specifically developed to measure the effectiveness of a lubricant in various metal deformation processes, are of limited use in the assessment of the total performance of a lubricant in a press forming operation and can only be used as an initial guide in the selection of a suitable lubricant.

BLUESCOPE STEEL

ACKNOWLEDGMENT
Table 1 and some of the text in this bulletin are based on information contained in "Metals Handbook", Volume 4, by kind permission of American Society for Metals.

Acknowledgment also goes to Richard Hole, Product Designer of Richard Hole Lubricants Pty Ltd NSW, for assistance in preparation of this document.

Please ensure you have the current Technical Bulletin as displayed at www.bluescopesteel.com.au

BlueScope Steel

BlueScope Steel Limited ABN 16 000 011 058
BlueScope Steel (AIS) Pty Ltd ABN 19 000 019 625

9 320075 034863

AUSTRALIA	
SYDNEY	Telephone: (02) 9795 6700
MELBOURNE	Telephone: (03) 9586 2222
BRISBANE	Telephone: (07) 3845 9300
ADELAIDE	Telephone: (08) 8243 7333
PERTH	Telephone: (08) 9330 0666

OVERSEAS	
BlueScope Steel (Malaysia) Sdn Bhd	Telephone: (603) 3250 8333
BlueScope Steel (Thailand) Limited	Telephone: (66 38) 685 710
PT BlueScope Steel Indonesia	Telephone: (62 21) 570 7564
BlueScope Steel Southern Africa (Pty) Limited	Telephone: (27 21) 555 4265

BLUESCOPE STEEL

Produced by Artimprint (02) 9984 8586