MACSTEEL VRN

STRUCTURAL STEELS
MACSTEEL VRN T690

Macsteel VRN T690 is a roller quenched and tempered alloy steel designed to provide an excellent combination of high strength (690 MPa minimum yield strength), toughness, abrasion resistance, and weldability.

This improvement in physical properties of Macsteel VRN T690 is obtained through increased alloy content which results in increased hardenability.

MECHANICAL PROPERTIES	
Minimum yield strength at 0.2% offset (MPa)	690
Tensile strength (MPa)	760-895
Minimum elongation in 50mm (%)	18*
Minimum reduction of area (%)	40**, 50**
Brinell hardness, typical	235 / 293
Toughness properties may be specified:	

* A deduction of 1.255 per cent may be made for each decrease of 0.8mm of specified plate thickness under 8mm, up to a maximum deduction of 3 per cent.
** If full-section flat specimens are used, 40 per cent applies. If a standard, machined round specimen is used, 50 per cent applies.

TYPICAL CHEMICAL COMPOSITION (MAX)

C.	Mn.	Si.	S.	P.	Cr.	Mo.	Ni.	B.
0.12 / 0.21	0.45 / 0.7	0.2 / 0.35	0.04	0.035	0.85 / 1.2 60 - 150mm	0.5 / 0.65	1.2 / 1.5 38 - 150mm	0.001 / 0.005

TYPICAL MECHANICAL PROPERTIES

Normal Thickness (mm)	Tensile Strength (MPa)	Min. Yield Strength (MPa)	% Elong in 200mm (Min)	Impact Strength J (Min)
6 - 150	760 - 895	690	18 (in 50mm)	-

FABRICATION

Cold forming

Macsteel VRN T690 steel plates can be readily formed or bent at atmospheric temperature if adequate power is available and proper procedures are used. Generally, the power required to form Macsteel VRN T690 will be three times that required for carbon structural steel.

The springback after forming is also considerably greater than on carbon structural steel and due allowance must be made. A trial run may be necessary to determine the springback allowance for close tolerance work. The suggested minimum inside radius for forming Macsteel VRN T690 steel plate is given below:

Plate thickness (T) in mm	Minimum inside Radius
Up to 25mm, inclusive Above 25 to 50mm, inclusive	2T 3T

The following precautions should be taken for bending operations:

1. **Use the largest radius permissible.**
2. **Major bends should be made on a line which is perpendicular to the length of the plate (rolling direction), if possible.**
3. **The outside radius should not be restrained. Closed-die forming may require doubling the suggested radii to avoid breakage.**
4. **For press brake forming, the lower die span should be at least 16 times the plate thickness. If design requirements will not permit this, the bend should be started with an upper die of larger radius.**
5. **The minimum tensile requirements (790 to 930 MPa) should be waived whenever severe forming is anticipated. This will enable us to produce the lowest possible yield strength consistent with the specification.**
6. **Sharp notches on the edges of plates resulting from shear breaks or torch cutting may require removal by grinding or machining to prevent cracking during severe forming.**
7. **Roll forming of cylindrical sections should be preceded by crimping of the butt edges.**
8. **Extremely severe forming should be done after heating the plate to 540 / 595^{O}C.**
9. **Deep scratches or gouges on the outside radius may cause cracking on severe bends. This condition may be corrected by grinding out or buffing the scratches.**
10. **6 - 32mm Grade AD**
    38 - 50mm Grade AE
    60 - 150mm Grade AF

Shearing

Macsteel VRN T690 steel plate can be cold sheared up to and including 25mm thickness if the capacities of the shear and the shear knives are adequate. A shear capable of cutting 38mm carbon structural steel is required to shear 25mm plate of MacsteelVRN T690 steel. The capacity of smaller shears would be down rated in proportion, i.e., the capacity is decreased about 33 per cent when Macsteel VRN T690 is sheared.

The clearance on the shear knives should be less than the conventional 5 per cent of plate thickness, usually about 2 per cent. A compromise clearance to accommodate all plates from 6mm to 25mm in thickness would be about 0.4mm. Knives should be kept sharp to avoid ragged edges.

Punching

Holes may be punched in Macsteel VRN T690 plates up to and including 12mm in thickness as long as the hole diameter is greater than the plate thickness. Punch and die clearance should be close, as described for shearing, and the tools should be kept sharp. Greater thicknesses can be punched; however, excessive punch wear may result.

Machining

Macsteel VRN T690 steel plates can be machined with conventional equipment using either high-speed steel or carbide tooling. Because of the relatively high hardness of Macsteel VRN T690 steel as compared to carbon structural steel, the cutting speeds should be about 30 per cent less in order to obtain reasonable tool life.

A coolant should always be used if available as an aid to tool life. When extensive machining is necessary on torch cut edges, it may be found essential to soften the edges. This can be done by tempering the entire plate, or only the edges, in a temperature range of approximately 540^{o} to 595^{o}C.

Torch cutting

Macsteel VRN T690 steel plate can be cut with conventional oxygen fuel gas equipment without the necessity of preheating or postheating, employing the same practices used for soft carbon steels. Stack cutting of plates, however, should be avoided because of excessive heat inputs required.

As with any structural steel, the smoothness of the cut is affected by scale on the surface of the plates.
Plasma-jet torch cutting is suggested wherever available and is advantageous because of the high cutting speed, the smoothness of the cut, and the shallow heat-affected zone produced.
On multiple cuts, balanced torch settings will help avoid distortion.

WELDING

General

The Macsteel VRN T690 low alloy grades of steel were developed to be easily weldable. High strength in structural steels may be achieved either by addition of alloying elements or by thermal treatment, as with the Macsteel VRN T690 steels. They are quenched and tempered and contain a minimum of alloying elements which render them easily weldable.

Most of the well known fusion welding processes may be employed on Macsteel VRN T690 steel. Fusion welding involves depositing molten weld metal in order to achieve a joint. The chemical analysis and the cooling rate of the weld metal can be controlled. However, the region directly adjacent to the weld on either side, known as the heat-affected zone (HAZ), experiences a thermal cycle, ranging from unaffected parent plate to near melting at the fusion boundary. Since the chemical analysis of the parent material is unalterable, it is important to take care of the thermal cycle of the HAZ. When welding Macsteel VRN T690 plate a number of general factors have to be borne in mind.

The main source of concern in welding these steel is hydrogen induced cold cracking. By minimising the sources of hydrogen and by avoiding the formation of a crack-sensitive microstructure and also by keeping stresses below certain limits, hydrogen induced cracking can be avoided. In addition, for full strength buttwelds a suitable welding consumable must be selected.

Sources of hydrogen

Dirt, grease, paint, moisture, rust, etc., on the plates to be welded should be positively removed.
The welding consumables should be of approved quality and should be clean and dry, during both storage and usage. Different welding processes have different inherent hydrogen potentials. When welding with the processes of highest hydrogen potential, greater care is required than welding with processes of lower hydrogen potential.

Avoidance of crack sensitive microstructure.

The microstructure in the HAZ is determined by the steel composition as well as the local cooling rate.
A knowledge of the steel composition is therefore essential for proper selection of welding parameters. The use of the Carbon Equivalent formula gives an indication of the degree of care required.

The CE of Macsteel VRN T690 ranges between 0.37 and 0.54. In order to avoid a crack-sensitive microstructure, a suitable cooling rate in the HAZ must be maintained after welding. Generally this involves using pre-heating and controlled values of heat input during welding. The particular values of pre-heat and heat input depend upon a number of factors but average values are quoted below in Table 1. Heat input can be calculated from the formula.

$$HI = \frac{\text{Welding volts (V) x welding current (Amps)}}{\text{1000 x welding speed mm/sec}} = \frac{\text{kJ}}{\text{mm}}$$

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{5}$$

It should be emphasized that the values of pre-heat and heat input quoted in Table 1 are average values. Factors such as restraint, welding position, edge preparation, service conditions (type of load), etc., may influence the particular values elected.

Welding stresses

In general it may be stated that joints of high restraint need more care when welding than joints of low restraint.

This is of particular importance when using a strength filler material in order to achieve a full strength joint.
The molten weld metal contracts upon cooling if free to do so, causing distortion, or creating welding residual stresses of yield point magnitude if free contraction is hampered. Values of high residual stress are conducive to distortion during subsequent machining operations and cracking in the weld or HAZ during and after welding. Welded structures should be designed for welding in order to minimise the volume of weld metal which should be deposited in the shortest possible time to effect the greatest economy.

Summarising, it may be stated that Macsteel VRN T690 is a weldable quenched and tempered steel which may be successfully welded with the common fusion welding processes provided certain precautions are taken. The level of hydrogen in the deposited weld metal should be kept to a minimum, the cooling rate must be slow enough to avoid the formation of crack-sensitive microstructures in the HAZ but not so slow that excessive grain growth occurs. Pre-heating and controlled values of heat-input are therefore required.

Welding consumables

The American Welding Society Classification AWS EXXXX is a very practical and useful system. British and South African equivalents may be found in BS 639 and SABS 455 respectively. For practical reasons, only the AWS classification groups are quoted here.

Matching strength consumables are suggested for welding Macsteel VRN T690 although lower strength consumables can be used. Consumables should conform to one of the following specifications: S.M.A.W.: A.W.S. A5,5, E 9018 or E 11018; G.M.A.W.: A.W.S. A5,28, ER 90S or ER 100S

AVAILABLE CONSUMABLES FOR WELDING MacsteelVRN T690

SUPPLIER	S.M.A.W. (MMA)	G.M.A.W. (MIG - CO_2)
AFROX	Transarc 98 Transarc 118	Transarc 6048
ESAB	OK 75.75	
EUTECTIC	EUS 110	-
FEDGAS	Griduct 17	Fluxofill 42
OERLIKON	Armcor LH	Acros Arc 110t
ROCKWELD	Ductilend 110	MaKay 117

Heat input schedule

Stress relieving

It is generally felt that stress relieving of welded joints is not necessary. Stress relieving for prolonged periods of time at relatively high temperatures, can cause metallurgical changes which are detrimental to the mechanical properties of the steel. The table shows that 12mm Macsteel VRN T690 does not seem to be susceptible to these metallurgical changes.

However, it is suggested that stress relieving at about 600^{o}C be limited to a maximum period of 2.4 minutes per millimetre of thickness. Longer periods of exposure would be permissible at lower temperatures.

Effect of prolonged exposure during stress-relief on mechanical properties: 12mm plate Macsteel VRN T690

stress-relief (SR)	0.2 % proof stress (MPa)	Tensile strength (MPa)	Elongation in 50mm %	Reduction in area %
Quenched and tempered	783	821	22.3	67.6
SR 1 hour at 538^{o}C	762	808	22.3	67.7
SR 8 hours at 538^{o}C	767	821	23.0	67.2
SR 24 hours at 538^{o}C	770	821	22.9	65.9
SR 100 hours at 538^{o}C	790	836	22.4	66.5
SR 1 hour at 593^{o}C	765	814	22.5	66.9
SR 8 hours at 593^{o}C	760	808	23.0	66.2
SR 24 hours at 593^{o}C	770	814	22.0	65.9
SR 100 hours at 593^{o}C	711	759	22.2	65.9

Heat input schedule for all grades

PLATE THICKNESS	COMBINED THICKNESS*	MINIMUM PRE-HEAT ^{o}C	MAXIMUM HEAT INPUT VALUES kJ/mm
10	20 30 40	35 35 35	1.0 - 1.5 1.0 - 1.5 1.0 - 1.5
20	40 60 80	50 50 80	1.0 - 2.0 1.5 - 2.5 1.5 - 3.0
30	60 90 120	50 80 100	2.0 - 3.0 2.5 - 3.5 2.5 - 4.0
50	100 150 200	80 100 125	2.5 - 4.0 2.5 - 4.0 2.5 - 4.0

* The combined thickness of a joint is the total thickness (mm) of the plates meeting at the joint line.

Applications

Macsteel VRN T690 is a very high strength structural steel and can result in greater load carrying capacities and lighter structures when used in place of conventional structural steels. Uses include:

- **Earthmoving equipment**
- **Dump trucks**
- **Trailers**
- **Mobile cranes**
- **Drilling rigs**
- **High speed fans**
- **Bridges**