THE COST OF WELDING HIGH STRENGTH STEELS

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Presented to the

Institute of Road Transport Engineers of New Zealand

FIFTH INTERNATIONAL HEAVY VEHICLE CONFERENCE

AUCKLAND

19-22 APRIL 1994

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ABSTRACT

This paper summarises some aspects of a New Zealand Welding Centre research project on design and fabrication with High Strength Steel (YS≥ 450 MPa). It covers current New Zealand usage of HSS, aspects of welding process selection and the cost of welding, some experiences related to the application of AS 1554.4. It lists several conclusions drawn from the project.

1. INTRODUCTION

1.1 New Zealand and Australian Usage of High Strength Steel

Economic considerations in steel construction highlight the need for the use of materials able to support high service stresses, and to offer through their ductility an acceptable resistance to brittle failure under loading conditions. This requirement has to be combined with easy formability and weldability (Fig. 1.1). High strength steels (HSS) (min yield strength ≥450MPa) fulfill these requirements and may also offer potential cost savings compared with ordinary carbon steel:

- in material cost savings through improved strength to weight ratio
- in welding cost as a result of reduced weld sizes
- operating cost as a result of weight savings (eg in the transport industry)
- reduced cost for preheat when compared with conventional heat treatable steels with similar strength level
- increased abrasion resistance as a result of increased hardness.

These advantages have lead to a considerable increase in the application of HSS overseas, but to a lesser extent in New Zealand. Reasons for this lower level of usage are lack of knowledge of the advantages of these materials, limited availability of a suitable material range, and lack of know how relating to fabrication and, particularly, welding.

It is difficult to obtain reliable data on New Zealand usage of weldable HSS. Fig 1.2 shows the usage of plate steel grades which make up the large majority of HSS in New Zealand. Compared with the current standard 250 MPa min. yield strength grade, the proportion of the higher strength grades (>450 MPa min. yield strength) is very small (about 5%).

It is significant that the medium strength 350 Grade is also under represented although this Grade is already well covered in design and fabrication codes. With BHP New Zealand Steel now having this plate grade readily available and stocked in New Zealand, a significant increase could be expected within the next few years.

In the high strength range covered in this investigation the grades between 350 and 690MPa yield strength are not used in New Zealand. Reasons for this are lack of availability (not available ex stock) and lack of coverage of these grades in design and fabrication guidelines generally recognised in New Zealand.

Although some overseas manufacturers produce sections with over 450 MPa min yield strength we are not aware of any New Zealand usage. Typically sections are made up by welded construction from plate.

As discussions with the major users of HSS in New Zealand show, hardly any usage goes into the building industry. Main usage of plate is for the transport industry, for products such as container transport trucks, logging trucks or supporting lifting gear. However, considerable usage has also been reported for heavy machinery such as wool presses.

Fig 1.3 shows the usage of plate steels for Australia. On a comparision by population base Australia has approximately 5 times the population of New Zealand. However Australia's steel usage is approximately 8 times that of New Zealand. This represents a 60% higher usage, probably as a result of a higher level of engineering activity in Australia. Comparing the grades of plate steel it is interesting to note that the amount of higher strength quenched and tempered steels (Q&T) is identical with the usage in New Zealand. Neglecting the boiler grades (typically ≤ 350) and the plate specified under "other" it is interesting to see that the 350 Grade is about three times more used in Australia than in New Zealand. With improved availability of the 350 Grade a similar usage can be expected in New Zealand.

1.2 Definition of Weldable High Strength Steels

The definition of what exactly are weldable high strength steels is not fully clear. We obviously understand that they must be of higher strength than the classical structural mild steels which typically go up to a minimum yield strength of 450MPa. They must be readily weldable, which means the application of no preheat or a only limited amount of preheat; post weld heat treatment should be the exception rather than the rule. This weldability rule excludes, for example, high carbon steels (carbon contents > 0.5) or the heat treatable low alloy (HTLA) steels from this range of high strength steels.

Looking at the coverage of structural steel welding by codes there appears to be a typical cut off point for welding of steels of higher strengths (Fig. 1.4). Both the New Zealand standard NZS 4701:1981 [1] and the Australian standard AS 1554.1:1991 [2] for structural steel welding have their cut off point at a minimum yield strength of 450 MPa including steels typically classified as low carbon and high strength low alloy (HSLA) steels.

However the Americans, in the AINSI/AWS D1.1-90 Structural Welding Code [3], allow the minimum yield strength to go to 690 MPa including HSLA and Quenched and Tempered steels. BS 5135:1984 [4] is not specific about strength limits and is applicable to carbon and carbon manganese steels.

Considering strength properties achievable by different groups of steels exceeding the minimum 450 MPa yield strength requirement, and combining this requirement with appropriate weldability, the steel groups included in this definition of weldable high strength steels are:

- High Strength Low Allow Steels (HSLA)
- Quenched and Tempered Steels (Q&T)
- Thermo-Mechanically Treated Steels (TM)

Figure 1.5 compares these groups of steels in respect to their typical strength range, carbon equivalent (CE), preheat requirement, and notch toughness.

2 COST COMPARISON

As outlined in the introduction, HSS may offer a number of economic advantages. Some of the savings relate straight back to fabrication such as material cost savings through reduced weight, or lower welding cost as a result of reduced weld size. Other savings can be classed as secondary savings such as in erection cost or in actual running cost as a result of weight savings.

The cost comparison as outlined here is based on New Zealand specific data. The prices are list prices ex stock unless otherwise stated. Considerable price concessions may be available to the major consumers. Also, particularly for the welding cost, methods used by the individual fabricator may differ and it is therefore always advisable for the potential user to establish their own cost for a truly relevant comparison. However, as a first indication, this comparison points out the significant cost relationships between the alternative steel grades and welding processes offered.

2.1 Material Cost

As outlined in Fig 1.2, in New Zealand only a limited range of HSS Grades are available ex stock. However it can be assumed, as all grades are currently imported from overseas, that alternative grades if ordered in a reasonable quantity are very similarly placed in their cost. In New Zealand, based on the experience during this project, designers are advised to check at the planning stage what grades and what thicknesses are indeed available ex stock. This avoids redesigning components as a result of lack of availability. It is also advisable to check exactly on the details of the material supplied and in critical applications always to ask for material certificates. It appears that there is some inconsistency in specifying the actual properties of the different grades. For example some sales literature lists typical properties of the grades in a manner which could be interpreted as the relevant ones for design purposes. In one case this could amount to an 11% difference in yield strength. Designers are advised to use the nominal specified minimum yield strength depending on the material thickness. This is the yield strength actual guaranteed by the supplier.

Fig 2.1 compares different plate materials on the basis of equivalent yield properties. To achieve equal yield properties the 250 Grade material requires in the example 35mm plate thickness while the comparable 690YS plate only requires a thickness of 12.7mm. This is a saving in weight of over 73%. Taking the actual plate cost into account for similar performance under the ideal tensile stress application, the 690 HSS grade costs only 57% of the comparable 250 Grade. Especially if considering additional cost factors such as handling it is obvious that the higher strength grades compare very favourably.

In this context it should be noted that the readily available 350 Grade, well covered in current design and welding codes, achieves 25% possible savings in cost, providing a very attractive alternative to the commonly used 250 Grade. With approx 34% savings potential the 450 MPa alternative appears to be even more attractive.

As outlined in the chapters on design, it should however be noted that the full weight savings advantages can only be achieved in the ideal case of tension loading. As a result of reduced thickness eg the achievable buckling strength in the case of compression is also reduced.

2.2 Welding Cost Comparison

In order to obtain an appreciation of welding cost for HSS two types of comparisons are described.

The first cost comparison compares the commonly used welding processes MMAW, GMAW and FCAW for identical welding tasks. The second comparison is based on the assumption that equal strength welds have to be achieved, using the GMAW welding process as the basis of comparison.

2.2.1 Welding Process Comparison

The welding process comparison is split into two representative welding tasks, the welding of a single sided V-butt joint welded from both sides in the flat position, and a vertical up fillet joint. Both welds are to AS 1554.4.

Figure 2.2 compares the cost of the consumables used. Note the costs are based on consumables with matching strength, which means in the case of GMAW and FCAW significantly higher cost than the comparable lower strength fillers as a result of the required alloying additions. The FCAW wire chosen is an all positional flux cored wire equally suitable for the downhand and vertical up welds used in the comparison. The shielding gas mixture Ar-20% CO_2 was as recommended for both the GMAW and FCAW wires used.

Figure 2.3 lists the input data to determine labour and equipment cost.

The MMAW power source chosen is a low cost AC/DC power source. The GMAW pulsed power source minimises set up times and spatter development producing a low spatter, smooth profile weld. For the FCAW process a low cost standard GMAW power source is chosen as this type of source produces acceptable welds with FCAW wires.

Note that the operator factor, at 0.8 (80% of time is productive time), is set high as the cost calculation system used takes account of process specific ancillary times such as electrode change which are usually incorporated into the operator factor.

Figure 2.4 lists the ancillary time elements considered in the cost calculation for each of the processes.

Figure 2.5 shows the results of the cost comparison of butt welds made in 12mm plates of a Grade 800 TS Q&T steel. Due to the relatively low cost of the matching strength MMAW electrodes the difference between MMAW and FCAW is less significant and MMAW proves only to be approximately 6% more expensive for this welding task. However FCAW and MMAW are both 50% more expensive than GMAW as a result of the higher consumable cost and the higher cost for deslagging (considered in ancillary labour). The FCAW wire classed as easy slag removing required significant time for the slag removal of the root run, although the subsequent runs were less time consuming for deslagging. As the FCAW wire was of the all positional type, the deposition rate achieved for the downhand was slightly lower than for the solid wire GMAW pulsed process.

In this context it should be noted that for V-Butt joints welding codes generally require a slightly larger included angle for the MMAW weld preparation versus the GMAW and FCAW preparations. E.g. AS 1554.4 requires for the joint B-C2a the MMAW included angle to be 60° with a 3.5mm gap and a 1.5mm root face for all positions.

The FCAW preparation for the downhand position requires a 3mm gap and 3mm face and a 50° angle. The GMAW spray position requires a face of 4mm with no gap and a 50° included angle. These prequalified preparations appear to disadvantage the FCAW process which, as the comparison shows, can be safely applied with a broad face and no gap as for the GMAW spray process. Fig 2.6 compares welding cost for the differing joint preparations.

Following the code requirements, FCAW requires approximately twice and MMAW three times as much weld metal as GMAW. As a consequence of this welding costs are also considerably higher and it is worth while to evaluate alternative joint preparations if MMAW and FCAW is considered such as B-C 2d to AS 1554.4 as used in the cost comparison for equal strength.

Figure 2.7 shows the results for the vertical up fillet welds. The comparison shows less significant cost differences between the three processes with an advantage for the GMAW-P alternative.

2.2.2 Cost of welds of equal strength

This comparison is based on the same material selection criteria as used in the material cost evaluation. Equal strength welds have to be achieved with different strength materials grades i.e. 250, 350, 450 and 690 MPa Yield Strength. Figure 2.8 and 2.9 summarise the results of a comparison of double V-butt welds welded from both sides with GMAW spray transfer (1.2mm Ø).

In Figure 2.8 are shown the theoretical figures for required weld metal based on joint B-C3 to AS 1554.1 and AS 1554.4. While it is apparent that savings in weld metal cost in the low cost GMAW filler grades 250-450 are significant, the high strength 690 filler still gives significant filler cost savings against the 250 Grade (56%) and against the 350 grade (6%).

However, filler metal cost is only one part of the total welding cost. In Figure 2.9 the cost established in workshop trials in the 250, 350 and 690 yield strength grades are shown. Due to unavailability the 690 plate was only 12mm instead of 12.7mm and to compensate the reinforcement was increased by approximately 0.7mm. Also the included angle of the weld preparation was increased from 50^{o} to 70^{o} to ensure adequate fusion, consequently increasing welding cost for the thicker materials.

With 68% weld cost savings compared to the 250 yield strength alternative the savings potential is very high. The more welding a structure involves the more attractive a HSS alternative looks from a welding cost point of view. If this is combined with the additional material cost savings potential HSS alternatives are indeed worth while investigation. However it should also be highlighted that the 350 Grade with 36% weld cost savings offers a very attractive alternative particularly when lower thicknesses not requiring preheating are welded.

3 CONCLUSIONS

Without giving an order of priority the following is a list of conclusions deduced from the comprehensive project work which is covered in full in [5].

- Current New Zealand usage of HSS plate (> 450 MPa yield) is low with approximately 5% of the total plate market. Availability of steel plate ex stock in the middle strength range ~ 450 MPa is limited. The 690 MPa yield strength range is well stocked and used.

- To understand HSS fabrication a detailed knowledge of HSS metallurgy is desirable. Concepts of carbon equivalent (CE_{IIW}, P_{CM}, and CEN), preheat determination and cooling rate (t8/5), welding heat input, hydrogen embrittlement, consumable selection and control are only a few of the aspects which need to be well understood.

- Designers and fabricators alike need to be fully aware of the fatigue properties of welded joints. Full advantage of HSS for welded fatigue application can only be achieved if fatigue improvement methods are applied. Practical workshop techniques such as toe grinding, TIG-dressing and peening can be applied. Attention to detail is a must.

- Fabrication including cutting, drilling, milling and forming do not cause specific difficulties. However fabricators have to be aware that settings, such as preheat level or cutting speed in oxyacetylene cutting, tool geometry, feed rates and spindle speeds for drilling and milling, or forces required for forming and shearing are different. Machinery and tools need to be suitable for the stronger and generally harder HSS materials.

- HSS are typically applied where advantages of the extra strength are expected. This usually implies that the applications require high integrity of the welded joints except maybe for some wear application. Suitable codes are available to cover all aspects of welding fabrication with these materials.

- Welding skill level required is not higher than for mild steel welding, however it is desirable that welders and supervisors fully understand the specifics of these materials. Without exception welding should only be done to qualified procedures.

- Consumable control is a most basic requirement particularly for low hydrogen electrodes, but also for FCAW wires and SAW fluxes.

- Selection of welding process is important if economy is a consideration. The GMAW solid wire process can offer significant cost advantages over MMAW and FCAW based on today's consumable cost and achievable deposition rates.

- These savings in welding cost are most significant when welds of equal strength are compared for different strength grade materials. A 12mm butt joint in 690 yield HSS, if compared to the corresponding 35mm butt joint in 250 yield mild steel under tension, would lead to material cost savings of 43% while the welding cost savings would be approximately 68% (based on the GMAW process).

- Consideration of the design of statically loaded steel structures has identified the situations where high strength steel could be used to advantage. These situations are usually when the design is controlled by steel strength (rather than deflection, buckling, or geometrical limitations). However, high strength steel can also offer benefits when reduced steel weight or smaller/thinner section sizes are beneficial.

- Because the design of high strength steel structures is not included within the scope of New Zealand codes its use will be subject to the approval of the relevant authority. However, the results of overseas research can be used in conjunction with the New Zealand Steel Structures Standard (NZS 3404:1992) for design of common elements using high strength steel.

- Case studies involving design of steel gravity columns using various grades of steel have shown that high strength steel can offer substantial weight and material cost savings, particularly for lower level columns in multi-storey buildings.

Although the fabrication and erection costs were not able to be quantified, it is expected from the case studies and general experience that significant savings are also available in these areas.

- A brief review of buildings and bridges constructed using high strength steel has confirmed the cost savings available and the fabrication and erection advantages of using high strength steel.

- When evaluating the economics of using high strength steel, it is important to consider not only the material cost savings, but also the associated time and cost savings during fabrication, transportation and erection.

- To maximise the benefits of HSS in the case of dynamic loading, stress concentrations must be 'designed away' or the notch sensitivity reduced. This implies that a greater effort in the design phase is necessary, in the stress calculations in particular, as the stress range and notch sensitivity of a single detail can degrade a whole structure.

- Modern steel developments, particularly with the advance of the TM steels, bring improved weldability, less crack sensitivity (less preheat, good toughness), combined with a good strength to cost ratio. These steels are currently not readily available in New Zealand, however if designers and fabricators alike recognise the advantages, their usage particularly in the middle strength range ~ 450 MPa yield will offer great economic benefits.

- The readily available 690 MPa yield strength Q&T steel range is undergoing continuous improvement in respect of weldability and formability. Additional Grades particularly in the 500, 600 MPa yield class are available in New Zealand on special order.

- Compared with ordinary carbon steel HSS fabrication is 'high tech' and requires attention to detail, a well educated workforce, and suitable equipment. The benefits in economic terms can be substantial with great potential for improved profitability, making the move to HSS fabrication a worth while investment.

4 LITERATURE

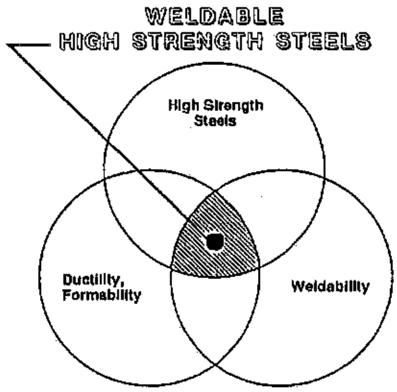
[1] NZS 4701-1981: Metal-Arc Welding of Steel Structures, Standards New Zealand

[2] AS 1554.1-1991: Structural Steel Welding, Part 1: Welding of Steel Structures, Standards Australia

[3] AINS/AWS D1.1-92: Structural Welding Code - Steel, American Welding Society

[4] BS 5135-1984: Process of Arc Welding of Carbon and Carbon Manganese Steels, British Standards Institute

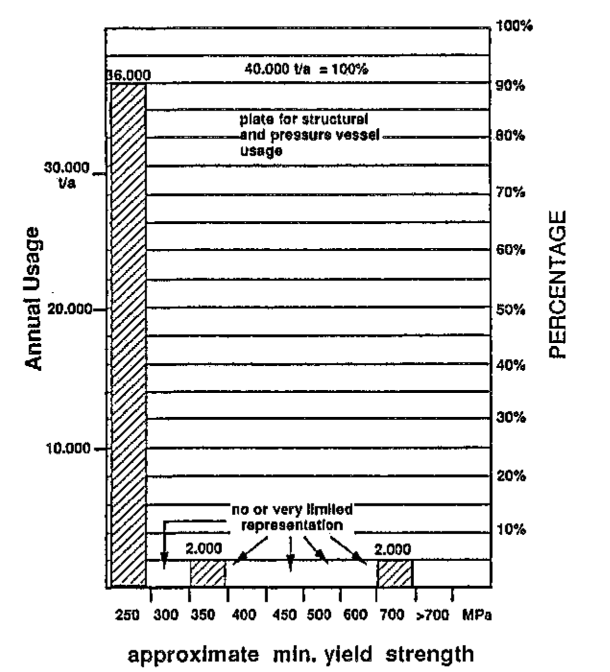
[5] High Strength Steel - Design & Fabrication - NZ Welding Centre Report R8-07, November 1992



Economy through

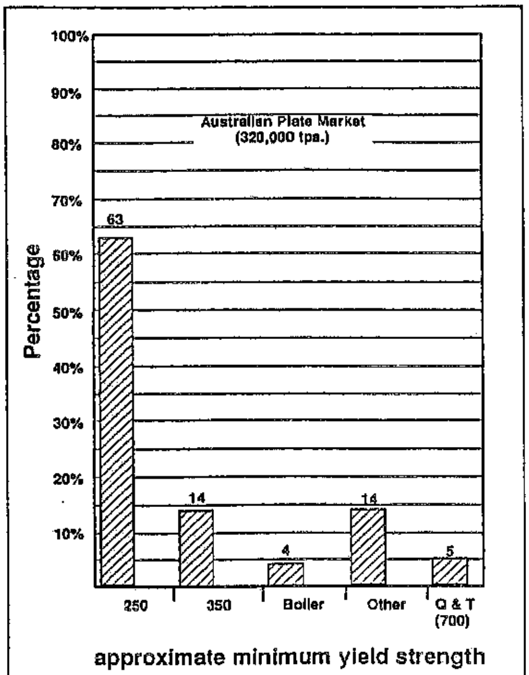
- excellent strength-weight ratio
  → material savings
  → secondary savings as a result of weight savings (eg. transport industry)
- reduced fabrication cost (compared to equal strength design in mild steel)
  → reduced weld size
  → reduced preheat (if compared to conventional normalised steels with similar strength)

Fig. 1.1
Weldable High Strength Steels - Advantages



SOURCE: HERA - Estimate for 1992 based on consultation with New Zealand suppliers

Fig. 1.2
New Zealand Usage Of Plate Steel Grades



SOURCE: Bisalloy Steels estimate

Fig. 1.3
Australian Steel Plate Market

CODE	HIGHEST MIN. YIELD STRENGTH	CE-LIMIT
NZS 4701:1981 Metal-Arc Welding of Steel Structures	≤ 450MPa	0.53%
AS 1554.1-1991 Welding of Steel Structures	≤ 450MPa	not specified
AS 1554.4 Welding of High Strength Q & T Steels	≤ 800MPa and comply with ISO 4950/3, ASTM A514, ASTM A517 or equivalent	not specified
ANSI/AWS D1.1-92 Structural Welding Code-Steel	Approved base metals with highest values ASTM A514:690 ASTM A517:620-690 ASTM A709:690	not listed
BS 5135:1984 Process of Arc Welding of Carbon and Carbon Manganese Steels	Not specified, Carbon and Carbon Manganese Steels	0.54%

Fig 1.4
Yield Strength And Carbon Equivalent Of Typical Structural Steel Welding Codes

	YIELD STRENGTH RANGE MPa	CARBON EQUIVALENT % x)	PREHEAT REQUIREMENT	NOTCH TOUGHNESS
HSLA	275-600	0.4-0.6	depending on thickness and grade none to max. 150°C	- poor in as rolled condition - good in normalised condition
Q & T	350-1000	<0.7	depending on thickness none to max. 150°C	- good
TM	350-700	<0.5	none to max. 80°C	- very good

HSLA = High Strength Low Alloy
Q & T = Quenched and Tempered Steels
TM = Thermo-Mechanically Treated Steels

$$CE_{IIW} = \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Ni + \%Cu}{15}$$

Fig. 1.5
Comparison Of Typical Properties Of Weldable High Strength Steels

APPROX. MIN. YIELD STRENGTH (N/mm²)	REQ'D PLATE THICKNESS, (mm) [Weight Savings (%)]	COST OF PLATE, [1] ($/t)	COST OF PLATE RATIO BASED ON EQUAL STRENGTH,(%) [Cost Savings (%)]
250	35mm Weight savings 0%	$1250 ≅ 100%	100%
350	25mm [28.4%]	$1320 ≅105.6%	75% [25%]
450 [2]	19.4 (20) [44.6%]	$1480 ≅ 118.4%	66% [34%]
690	12.7 (12)[3] [63.7%]	$1980 ≅158.4%	57% [43%]
960	9.1 [74%]	n.a.	n.a.

[1] Typical figure ex stock in N.Z
[2] Currently (1992) not available ex stock, price based on typical indent cost for HSLA grade.
[3] Figure in bracket shows closest available plate thickness.

Fig. 2.1
Comparison Of Different Grades Based On Equivalent Yield Properties

FILLER METAL			
Process	MMAW 5mm	GMAW 1.2mm	FCAW 1.2mm
Classification	AS 1553.2 E8318-M	AS 2717.1 ESM-GM-W769H	AWS 5.20 E110 T1-K3
Brand	Weldwell 118	Autocraft Ni-Cr-Mo	Dual Shield II 110
Material Cost	9.95 $/kg	12.90 $/kg	19.20 $/kg
Deposition Efficiency	60.4%	95.0%	87.0%
Stubloss Factor	13.5%	n/a	n/a
Material Factor (cost per cm³ of weld metal deposited)	0.45 $/cm³	0.11 $/cm³	0.17 $/cm³
SHIELDING GAS			
Type	n/a	Ar-20% CO_2	Ar-20% CO_2
Gas Cost	n/a	11.2 $/m³	11.2 $/m³
Flow Rate	n/a	14.0ℓ/min	14.0ℓ/min
Cost per Hour	n/a	9.40 $/h	9.40 $/h

Note: All figures are 1992 list prices exclusive of GST

Fig. 2.2
Welding Consumable Cost For Welding 690 YS Q&T Steel

LABOUR RATE 30 $/h
(incl. indirect cost such as holiday, ACC etc)

OPERATOR FACTOR 0.8
(to determine non productive time)

EQUIPMENT COST
(hourly rate)

Cost Factors	MMAW	GMAW-P	FCAW
Equipment Cost [$]	900	10,000	5,000
Depreciation [$/a]	90	1,000	500
Maintenance [$/a]	50	110	100
Interest [$/a] (10%)	45	500	250
Room [$/a]	250	250	250
Annual hours	1,600	1,600	1,600
Hourly Rate [$/h]	0.27	1.01	0.68

ELECTRICITY 0.15$kWh 0.15 $kWh 0.15 $/kWh

Fig. 2.3
Labour Rate, Operator Factor, Equipment And Electricity Cost

	MMAW	GMAW	FCAW
TIMES PER RUN - DEPENDING ON LENGTH			
Deslagging	100.0 sec/m	0.0 sec/m	100.0 sec/m
Repositioning Time	74.7 sec/m[1]	28.5 sec/m	74.7 sec/m[1]
Fatigue stop related times (torch, gloves, face shield picking up and putting aside)	8.8 sec/m	2.3 sec/m	4.8 sec/m
Electrode Change Time	92.0 sec/m	6.0 sec/m[2]	7.5 sec/m[2]
[1] includes time for repositioning for deslagging [2] relates to change of 15kg spool of wire			
TIMES PER RUN - INDEPENDENT ON LENGTH			
Pick up/aside face shield	6.1 sec	6.1 sec	6.1 sec
Position torch/electrode	3.4 sec	3.4 sec	3.4 sec
Pick up/aside hammer	5.4 sec	n/a	5.4 sec
TIME PER PROCESS - INDEPENDENT ON LENGTH			
Set current voltage, gas flow, etc	23.7 sec	33.7 sec	33.7 sec
TIME PER TASK			
Backgrinding small work piece	300.0 sec	300.0 sec	300.0 sec
Spatter removal	n/a	100.0 sec/m	n/a

Fig. 2.4
Time Elements To Determine Ancillary Cost

	GMAW Spray Transfer	MMAW	FCAW
Joint details - t	all	all	all
- Position	Flat	Flat	Flat
- Gap	0.0 mm	3.5 mm	3.0 mm
- Face	4.0 mm	1.5 mm	3.0 mm
- incl. angle	50°	60°	50°
Reinforcement[1]	2.0 mm	2.0 mm	2.0 mm
Weld metal weight[2]	0.318 kg/m	0.97 kg/m	0.674 kg/m
Deposition efficiency	95.0%	60.4%	87.0%
Stubloss factor	n/a	13.5%	n/a
Filler metal weight	0.33 kg/m	2.07 kg/m	0.77 kg/m
Filler metal cost/kg	12.90 $/kg	9.95 $/kg	$19.20 $/kg
Filler metal cost/m	4.26 $/m (100%)	20.60 $/m (347%)	$14.78 $/m (483%)
TOTAL WELDING COST[3]	**10.48 $/m** **(100%)**	**69.18 $/m** **(660%)**	**31.81 $/m** **(303%)**

[1] Reinforcement only on face side considered
[2] Excludes sealing run on the back as identical for all processes
[3] Cost based on settings as used for the cost comparison in Fig. 2.5

Fig. 2.6
Weld Cost Comparison For Joint Type B-C2a To AS 1554.4 - 1989

WELDING PROCESS TEST NO.	GMAW C1	MMAW C2	FCAW C3
Weld Type	V-Butt	V-Butt	V-Butt
Gap	0mm	0mm	0mm
Face	3mm	3mm	3mm
Incl. Angle	70°	70°	70°
Filler Metal Diameter	1.2mm	5mm	1.2mm
No. of runs (incl. backing run)	3	3	3
Average Travel Speed	0.340 m/min	0.148 m/min	0.204 m/min
Filler Metal Weight	0.666 kg/m	1.112 kg/m	0.774 kg/m
COST PER METRE			
- Welding Labour	4.45 $/m	10.13 $/m	5.59 $/m
- Ancillary Labour	6.47 $/m	10.49 $/m	9.38 $/m
- Non productive labour	2.73 $/m	5.15 $/m	3.74 $/m
- Equipment	0.53 $/m	0.23 $/m	0.43 $/m
- Consumables	10.20 $/m	11.34 $/m	16.76 $/m
- Preparation	not considered as identical		
TOTAL	**24.38 $/m** (100%)	**37.34 $/m** (153%)	**35.92 $/m** (147%)
Cost per kg of filler metal used	36.60 $/kg	33.58 $/kg	46.4 $/kg

Fig. 2.5
Single -V Butt Joint, Welded Both Sides, 12mm Plate, Flat Position

WELDING PROCESS TEST NO.	GMAW-P FVU 1	MMAW FVU 2	FCAW FVU 3
Weld Type	Fillet	Fillet	Fillet
Leg Length - nominal	10.0mm	10.0mm	10.0mm
- measured	10.0mm	10.5mm	10.0mm
Reinforcement measured	1.5mm	0.0mm	0.5mm
Filler Ø	1.2mm	3.2mm	1.2mm
Travel Speed	$0.063 \frac{m}{min}$	$0.038 \frac{m}{min}$	$0.062 \frac{m}{min}$
Runs	1	1	1
COST PER METRE			
- Welding Labour	7.94$/m	13.16$/m	8.07$/m
- Ancillary Labour	1.84$/m	8.10$/m	2.19$/m
- Non productive labour	2.44$/m	5.32$/m	2.56$/m
- Equipment	0.47$/m	0.24$/m	0.29$/m
- Consumables	11.22$/m	10.09$/m	14.20$/m
- Preparation	n/a	n/a	n/a
TOTAL	**23.91$/m** (100%)	**36.91$/m** (154%)	**27.31$/m** (114%)

Fig. 2.7
Fillet Weld, 10.0mm Leg Length, Vertical Up

SAMPLE STEEL	NZH 250	NZH 350		ASTM A 514 TYPE	
Yield Strength $\frac{N}{mm^2}$ (min)	250	350	450	690	960
Plate thickness					
- required mm	35	25	19.4	12.7	9.1
- ratio	100.0%	71.4%	55.4%	36.3%	26.0%
Cost of Plate[1] $\frac{NZ\$}{t}$	1250	1320	1480[2]	1980	n/a[2]
- ratio	100.0%	75.0%	66.0%	57.0%	
Weld Area[3] Double V mm²	269	135	71	32	14
(Reinforcement height) mm	(1.5)	(1.5)	(1.5)	(1.5)	(1.5)
Weight Weld Metal Ratio %	100.0%	50.0%	26.0%	12.0%	5.2%
Filler Cost $\frac{NZ\$}{kg}$	3.50[4]	3.50[4]	3.50[4]	12.90[5]	[6]
$ / m (dep. eff. 97.0%)	7.63	3.80	1.89	3.35	
Cost Ratio % Weld Metal	100.0%	50.0%	26.0%	44.0%	

Notes:
[1] Typical figure ex stock
[2] Not available ex stock currently
[3] Joint design to AS 1554.1 and 4
B-C3 GAP = 0
GMAW - Spray FACE = 3
Flat position incl. angle = 50°
[4] eg to AWS 5.18 ER 70-S6 or AS 2717.1 W 50 XH
[5] AS 2717.1 ESM-GM-W769H
[6] not available

Fig. 2.8
GMAW - Filler Metal Cost Comparison For Equal Strength Welds

SAMPLE STEEL	NZH 250	NZH 350		ASTM A 514 TYPE	
Yield Strength $\frac{N}{mm^2}$ (min)	250	350	450	690	960
Plate thickness					
- required mm	35	25	19.4	12.7	9.1
- tested mm	35	25	not tested	12.0	not tested
Joint Detail	Double V	Double V		Double V	
- Face mm	3	3		3	
- Gap mm	0	0		0	
- incl. angle	70°	70°		70°	
COST PER METRE					
- Welding Labour	19.36 $/m	9.38 $/m		2.33 $/m	
- Ancillary Labour	5.82 $/m	2.56 $/m		2.00 $/m	
- Non prod. Labour	6.99 $/m	3.64 $/m		1.65 $/m	
- Equipment	1.22 $/m	0.58 $/m		0.21 $/m	
- Consumables	15.97 $/m	8.30 $/m		4.70 $/m	
- Preparation	12.38 $/m	10.30 $/m		8.58 $/m	
- Preheating	not required	4.83 $/m		not required	
TOTAL	61.73 $/m	39.61 $/m		19.47 $/m	
	(100.0 %)	(64.0%)		(32.0%)	

Fig. 2.9
GMAW - Welding Cost, Flat Position, For Welds Of Equal Strength