38 - LIQUID METAL ASSISTED CRACKING OF GALVANIZED STRUCTURAL STEEL SECTIONS

INTRODUCTION

In excess of 300,000 tonnes of fabricated steel is hot dip galvanized in Australia annually and approximately 20 million tonnes is galvanized world-wide each year.(Note: This tonnage does not include continuously galvanized sheet, wire and tube). A significant proportion of this tonnage is structural sections.

In a very small number of instances in Europe, Asia and the USA, a phenomenon called liquid metal assisted cracking (LMAC) has occurred in the webs of larger structural beams. This phenomenon is also called cope cracking, as it arises in the coped sections of the beam webs.

There have been no recorded instances of LMAC occurring in universal structural sections in Australia. However, the potential for the development of cracks on what is a critical zone of these structural sections is an issue that needs to de defined in the interests of designers intending to use hot dip galvanized coatings for long-term protection of the structural sections used in their construction projects.

Crack propagated from angle frame after galva of arising from liquid m cracking.

INDUSTRY RESEARCH

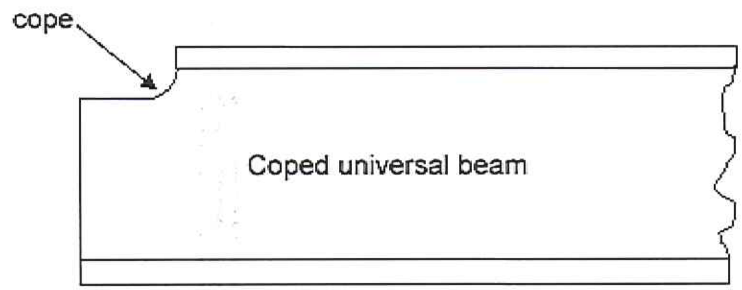
The infrequency of LMAC events and the somewhat unpredictable nature of the phenomenon have prevented conclusive research to be undertaken by interested industry oranisations. However, a significant amount of research has been done or is underway. The Galvanisers Association (GA) and the British Construction Steelwork Association (BCSA) in the UK, as well as the International Lead Zinc Organization (ILZRO) and the American Galvanizers Association (AGA) and other international industry groups in Germany and Japan are involved in ongoing research and investigation into LMAC phenomena.

These large galvanizec in Malaysia, have all be 'cope cracking' in the c

WHAT IS A COPE?

The illustration below shows a cope detail on a universal beam. Copes are oxy cut, usually in two operations. The first cut removed the top flange and a section of the web. The second operation cuts the cope radius and removes the remaining section of the web.

While LMAC in structural sections has generally been identified with copes, cracking may also arise where excessive stress has been induced in the steel through welding, oxy cutting or the punching of holes.



STEEL SUSCEPTABILITY
From research and case studies done to date, it has been recognised that there is a range of factors that can influence the initiation of LMAC, and there is a degree of synergy between some of the factors that may contribute to the phenomenon jointly, rather than individually.

Factors that have been identified as important as prerequisite for LMAC to occur are:

- the initial stress level of the steel
- steel chemistry
- steel section factors

The factors causing embrittlement of steel in the hot dip galvanizing process are well defined and understood. The most commonly encountered embrittlement problems associated with galvanizing are hydrogen embrittlement and strain-age embrittlement. The former arises with high strength steels (over 800 MPa) where they are acid pickled, allowing hydrogen to penetrate into the grain boundaries. This is independent of the galvanizing process itself, and will occur with any high strength steels that are pickled in acid in electroplating and other coating processes.

Strain-ageing embrittlement arises where steel of lower strength are severely cold-worked by bending or punching. The severely cold-worked steel 'ages' to a brittle state over time. The heat of the galvanizing process, or any other processes that heat the strained area such as welding, will accelerate the onset of embrittlement.

Liquid metal embrittlement is a less common cause of embrittlement that does not affect structural steels, and it should not be confused with LMAC. Stainless steels are particularly susceptible to liquid metal embrittlement in molten zinc, and the use of stainless steel elements in mild steel assemblies that are to be hot dip galvanized is not recommended.

FACTORS IN LMAC
In an ILZRO funded project (MTL 97-18) undertaken by the CANMET Materials technology laboratory found that steels below 415 MPa have a very low susceptibility to LMC. Where steels are oxy cut in the cope areas, usually requiring two operations as described above, considerable thermal sress can be induced in the heat affected zone (HAZ).

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A significant level of micro-cracking can occur on the HAZ of higher strength steels and these micro-cracks are the precursors of more significant cracking when further thermal stresses are induced in the hot dip galvanizing process, where the steel is raised from ambient temperate to 455oC in a very short time.

The form of the section is a factor here. The flange/web connection is a relatively heavy cross section and in many cases, the web/flange thickness ratio is less that 1:1. This results in differential heating at each end of the cope that may further increase the stress in this critical area while the section is immersed in the molten zinc.

Steel chemistry factors have also been identified as a contributor to LMAC susceptibility. Residual elements such as copper and tin and to a lesser extent, nickel and chrome, are known contributors to hot shortness in steel as they can come out of solution in the iron and migrate to the grain boundaries when the steel is heated to elevated temperatures of over 1000°C. The presence of these residual elements in steel are known to contribute to micro-cracking when the steel is heated to temperatures typically encountered when oxy-cutting.

Anecdotal evidence supports this. These residual elements commonly report in steel that is manufactures from scrap via the electric furnace process. Steel produced via the blast furnace route, using largely natural raw materials, have lower levels of these residual elements.

All steel structural sections (universal columns and beams) manufactured in Australia are produced via the blast furnace steelmaking process and there have been no reported incidents of LMAC with any of this material. Australia is unique in this respect as many other steel producing countries do not have the manufacturing processes for their steel sections so clearly delineated.

One known incident has been reported to Industrial Galvanizers of what appears to be an LMAC event on a light (100x100x10 mm) angle frame that had cracks propagating from the HAZ adjacent to the welds. All of these smaller merchant sections are produced from scrap-fed electric furnaces.

AVOIDING LMAC IN STRUCTURAL FABRICATIONS

The British Construction Steelwork Association has published a technical note, authored by its Technical Manager, David Moore, containing recommendations to minimise the risk of LMAC in galvanized structural sections.

These include;

- attention to design and detailing
- type and quality of steel specified
- fabrication techniques
- the galvanizing process and post-treatment and inspection.

If LMAC is identified in a structural section after galvanizing, procedures are available to remediate the affected area by gouging out the cracked area, re-welding and repairing the coating in the weld zone.

A hierarchy of factors has been listed in the BCSA's document which has been reproduced below.

Stress level	Material susceptibility	Liquid metal

Internal material stress	*Steel chemical composition*	Impurities
Cold deformation/prior strain	*Yield strength*	*Temperature*
Welding residual stresses	*Carbon equivalent*	Intentional additives
Restraint in the fabrication process	*Residual stresses from manufacturing processes*	
Thermal stress – immersion rate – variable section thickness – differential temperatures	*Hardness*	
Practical Factors		
Web/flange thickness ratio		
Welds – fillet/butt		
Depth of member (stiffness)		
Holes drilled/punched		
Member profile – section type/element		
Beam design		
Pre-heating procedures		
Presence of notches, inclusions and other steel defects		

SUMMARY
The rarity of LMAC occurring with Australian steels is an indication that the hot dip galvanizing of structural sections can be confidently undertaken. However, 35% of steel used by Australian fabricators and manufacturers is now imported, and the factors likely to initiate LMAC should be kept in mind when designing structures that are likely to be fabricated from steel structural section from sources other than Australian steelmakers.