Are unsafe “Fireproofing” practices still being used in Oil & Gas and Petrochemical Processing Plants?

Graham Boaler, Richard Holliday and Edward Walker

Decades after clear evidence of unsatisfactory performance emerged , some stakeholders still specify, supply and install an obsolete arrangement that may be inherently unsafe - namely hollow encasement, says MMI Engineering’s PFP experts; Graham Boaler, Richard Holliday and Edward Walker.

The pre-fire durability, explosion resistance, fire capability and reliability of the hollow encasement, "box", design fireproofing (figure 1) is found to be inherently flawed, but remains a preferred method with some stakeholders in Asia, Middle East, Europe and the United States. Here we discuss why the design is obsolete and reasons why the practice continues.

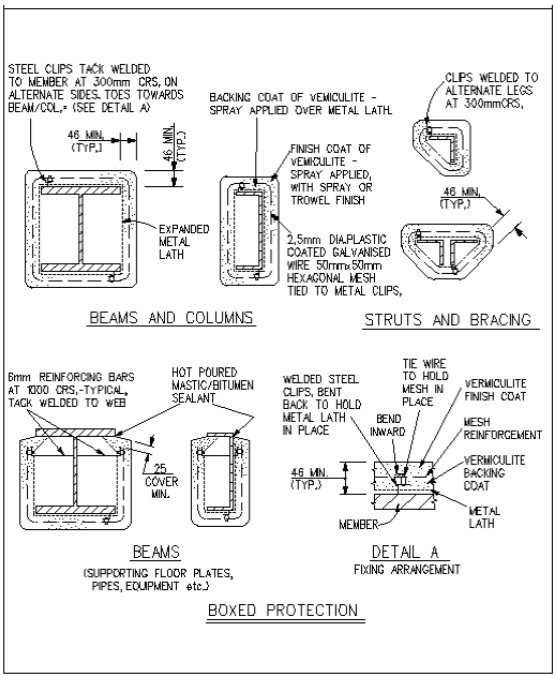

Figure 1 shows typical boxed “Fireproofing” arrangement details from a project specification.

1. Development of Proprietary Passive Fire Protection (PFP)

Although the first refinery in Europe opened 150 years ago it was in the, now mature, refineries and petrochemical plants of Europe and the United States opened circa 1920’s where the need for fireproofing, more correctly known as Passive Fire Protection (PFP), initially became recognised and was developed. The poor response to fire of steel structures and equipment prompted operators to provide protection that was provided typically by construction materials such as dense cast-in-place

concrete and masonry up until the 1960's. In the 1960's and 70's stakeholders collaborated in the development of proprietary products, where promising inorganic site mixes were developed into what are described and categorised by API [1] as Inorganic SFRM; Lightweight Cementitious Fireproofing (LWC).

2. Types of PFP Materials

American Petroleum Institute (API) provides categories (figure 2) of fireproofing materials in its guidance publication API 2218 [1].

6.3 Types of Fireproofing Materials
- *6.3.1 Dense Concretes*
- *6.3.2 Lightweight Concretes*
- *6.3.3 Spray-Applied Fire Resistive Materials (SFRM)*
  - *6.3.3.1 Organic SFRM*
  - *6.3.3.2 Inorganic SFRM*
- *6.3.4 Preformed Units Or Masonry*
  - *6.3.4.1 Preformed Inorganic Panels or epoxy PFP moulds / panels*
  - *6.3.4.2 Masonry Blocks and Bricks*
- *6.3.5 Endothermic Wrap Fireproofing*

Figure 2 API 2218 Types of Fireproofing Materials

3. Utilisation Summary

Oil, Gas and Petrochemical plants essentially comprise pipe-racks and equipment structures, equipment, buildings and storage vessels. All to a greater or lesser extent are vulnerable to the effects of fire.

There is a wide range of fireproofing materials available with the largest volumes being used to protect vessels, pipe-racks and equipment structures.

For such applications in onshore plant, inorganic LWC have been the preferred type globally.

This article considers the safe and inherently unsafe design of LWC on external plant and equipment structures in onshore petrochemical facilities.

4. Protection Techniques for Structural Steel Members

In considering LWC systems there are critical distinctions in performance between profile, box and solid fill methods of design as shown in Figure 3.

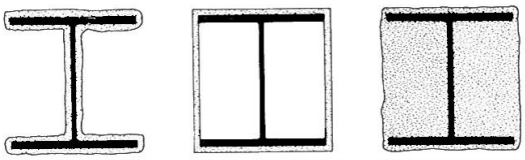

Figure 3 shows the generic design techniques for the protection of steel structures left to right; profile, boxed and solid fill (note solid fill designs are used on sections typically up to 203mm deep).

In profile and solid designs the coating is applied directly to the substrate whereas in boxed designs the coating is applied to a metal lath chassis.

It was a common practice in the 1960s and 1970s with site mixes and proprietary LWC to specify box designs that maximise commercial benefits when compared with dense concrete.

Because of a wealth of negative experience over decades in the pre-fire phase and in fire events boxed designs were effectively obsolete in external process plant in most of Asia, ME and Europe by 1983.

Over the last 50 years, there has been probably around 100 million square meters of LWC installed on process plant in widely varying climatic and operating regions in the world.

Considerable experience has been gained from in service feedback, product testing and development as well as reports from actual fires and explosions events.

This knowledge has been incorporated into the development of the current integrated LWC coating systems by four leading manufacturers.

"Recognized and Generally Accepted Good Engineering Practice" (RAGAGEP)

Over recent decades LWC profile and in limited cases, solid fill designs have come to be considered RAGAGEP and dominate PFP applications in the world today.

"While we look ahead to new materials systems and new operating provinces it's crucial to remember what we have learned on the way here. It's beholden on us to ensure that lessons learned from system failures in past incidents are not forgotten and disseminate experiences both resisters of change and learning practitioners in developing regions"(author unknown).

5. Fit for Purpose Quality

Cotgreave succinctly described the stakeholder's objectives and performance requirements in the report he wrote for the UK Health and Safety Executive; HSE OTI 92 606 [2].

"For a fully compatible and properly engineered system to be installed, attention to detail that ensures adequate quality and, at the same time, achieves a level of practicability commensurate with construction and operations, is required"(Dr T Cotgreave Shell Research Limited 1992).

PFP systems must meet many performance requirements in the pre-fire phase to be capable of performing in the fire phase in a predictable and reliable way. The extensive requirements may be categorised within the following headings:

- Installation Requirements
- Pre-fire Durability
- Maintenance
- Explosion Survivability
- Fire Performance (Pool and/or Jet)

(HSE OTI 92 606 [3])

6. Profile and Solid Fill Designs

Here we discuss aspects of pre fire durability, fire performance and explosion survivability.

Stakeholders have developed LWC over decades into integrated coating systems.

LWC are integrated coating systems from substrate via primer, corrosion protection coating system, retention system, fire protective material and topcoat, etc.

'Virtually all surfaces to which PFP systems are applied are liable to experience some degree of elastic flexure, vibration and thermal expansion and contraction in the normal course of events.

It is a fundamental requirement of PFP that it should remain firmly in place so that it can perform its intended task which in most cases requires that a bond is formed through to the steel substrate' (HSE OTI 92 606 [3]).

It is critically important therefore for a LWC to satisfy the numerous and onerous performance requirements a system must be in intimate contact with and firmly bonded to the substrate.

This objective can only be achieved with designs featuring the profile (or solid fill) configuration that achieves complete

intimate contact with the substrate. It is in this configuration that manufacturers have demonstrated the response of their systems to critically important performance requirements:

- Pre-fire Durability
    - Corrosion resistance
    - Mechanical damage resistance
- Blast loading response
    - Over-pressure
    - Drag forces
    - Substrate deflection
    - Projectile impact
- Response to characteristics of "real fires"
    - Jet fires
    - Impinging and engulfing pool fires
    - Fireballs from BLEVE events

7. Boxed Design: Problem Cause and Effect

The inherent weakness of the box design has direct effect on pre-fire durability, the whole life cost of ownership and fire event capability and reliability.

Pre-fire Durability

A "corner bead" component (figure 4) often galvanized steel sometimes plastic nosed, open leg, wire may be proposed as an application aid to form straight, square edges in boxed designs as shown in figure 5.

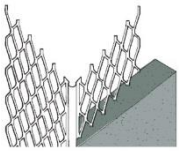

Figure 4
Galvanised steel angle bead detail

An angle bead detail has been found to be a particular weakness in the design. The detail is vulnerable to mechanical impact damage that results in a direct path for fluids into the arrangement.

Fundamentally a box design is significantly less capable of surviving mechanical impact and resisting elastic flexure and vibration than the profile and solid fill designs.

The resulting fractures provide a path for fluid ingress with resultant corrosion potential issues.

There are potentially two main sources of water under fireproofing and insulation:

- Condensation of atmospheric moisture due to thermal cycling
- External sources such as rain, cooling tower discharge, condensate dripping from cold equipment above, steam discharge, process liquid spillage, etc.

Water and/or moisture will permeate the LWC arrangement wetting the steel and potentially filling the void space created by box design.

In box designs commonly an insulation material may be positioned in the voids under the LWC in the webs of beams and columns.

Water ingress will increase the weight of the structure and damage by freeze/thaw cycling will exacerbate the anomalies.

This moisture results in the potential to cause corrosion under insulation or "fireproofing" - commonly known as CUI or CUF. The severity of corrosion would depend upon the existence, quality and

condition of the coating system applied to the steel under the insulation and LWC.

Corrosion

Horrocks, Mansfield, Parker, Thomson, Atkinson and Worsley (2010) [2] 'state the potential degradation of plant and equipment due to age related mechanisms such as corrosion, and erosion is a key issue for industry'.

With regard to insulation materials under the LWC it is accepted the presence of insulation can lead to corrosion which is much more severe than would be expected if the material was not present.

There are several reasons for this to happen:

• The insulation creates a creviced area at the surface of the metal which can retain water

• The insulation itself may absorb or wick water

• The insulation material may contain or absorb contaminates (e.g. chlorides, salt, etc.) which increase the corrosion rate

API RP 583 [4] discusses corrosion under insulation and fireproofing in detail.

Further corrosion of the LWC system components (retention mesh, lath, corner beads attachments pins and clips) may also occur as shown in Figure 5 resulting in unpredictable response to fire and early failure of the LWC, often resulting in dropped object hazards.

Figure 5 shows typical anomalies; the corner angle bead has corroded, the coating is detached and mechanical damage has compromised the arrangement.

Fire Performance and Explosion Survivability

In 1978 ICI Petrochemicals Division reported [5] 'that their unfortunate experience has shown that the use of angle beads can have disastrous results in the integrity of a structure during actual fire conditions'. They commented that 'continued use of these angle beads could have disastrous consequences'. Figure 6 shows the angle bead breakdown at the corners has caused the system integrity to be compromised.

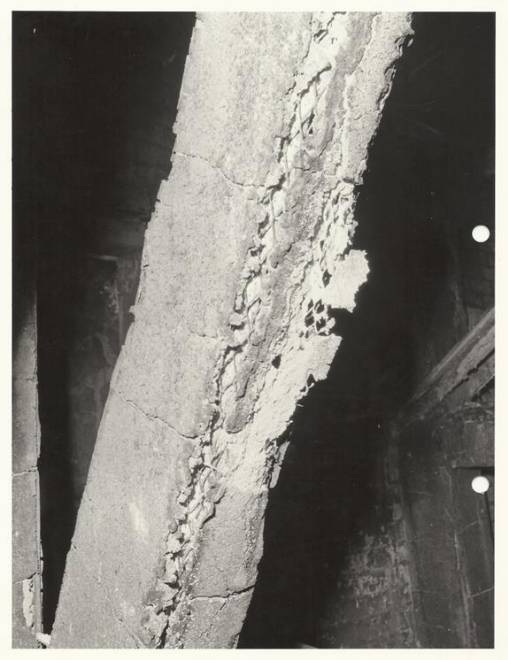

Figure 6 Premature failure of PFP due to effect of angle beads in a fire event in 1977.

Failures of boxed designed LWC resulting from over-pressures in explosions co-incident with fire events was detailed in a ICI Guide in 1982 [6] 'the explosion caused the fireproofing to collapse were there was a void behind the coating, this immediately made the protection ineffective against the ensuing fire'.

The comparative response of the designs to blast overpressures has been starkly illustrated in testing.

In the image Figure 7b the LWC on the boxed design has been destroyed, leaving the web exposed and rendering the arrangement ineffective in fire events, whereas the profile design remains intact and ready to perform its intended purpose in a fire event.

Figure 7a & 7b shows a blast loading response demonstration and the comparative performance of profile and boxed designs.

8. Three reasons why an inherently unsafe, obsolete practice persists?

Industry and operators standards, guidance and project specifications may not reflect credible design accident fire threats. Blast and jet fire may not be identified or considered in conjunction with each other.

Some of the stakeholders may not be aware of all the performance requirements and how completely a particular system

satisfies them with regard to reliability and capability.

Some suppliers and applicators promote obsolete boxed designs because of commercial aspects.

Fire Events and Risk Management

Global Safety Regulations and Guidance

Historically plants were regulated by reactive and activity based regulations. These were replaced in Australia and Europe with more rigorous performance based regulatory regimes. Recently the US Chemical Safety Board chairman, Rafael Moure-Eraso, called for the current patchwork of regulations in the US to be replaced with a similar performance based scheme.

An example of performance based regulation which implements the requirements of the European Community Seveso II Directive can be found in the UK Control of Major Accident Hazards Regulations 1999 (COMAH) [7],

Experience-based design rules (operator contractor or insurance guidelines)

Historically fire safety measures had been typically specified by reference to prescriptive codes and standards that provide standard solutions for a given set of plant parameters.

The change to performance based regulation and good engineering practices in the 80's and 90's have led to risk management that defines fire hazards and realistic fire scenarios that facilitates effective fireproofing scheme development.

However this change, originating in Europe, has not been completely adopted; some project stakeholders may still use a prescriptive rather than risk base schemes to develop the PFP specification.

Performance Requirements and Test Methods of Fireproofing

The fire performance of PFP systems are assessed in fire resistance tests that are intended to represent the effects of a real fire either hydrocarbon pool or jet [8 & 9].

However the prescribed furnace tests do not equate exactly to real fire events and should only be taken as a comparative indication of fire performance to a standardised test method.

For instance, the above tests will not demonstrate the capability, reliability and durability of arrangements to characteristics of real fire events:

- Protection against high momentum jet fires [9]
- Resistance to blast/explosion over-pressures and drag forces
- Resistance to hose stream/deluge

Confirming the obsolete status in 2007, there is no provision in the jet fire resistance test standard [10] for assessing a boxed structural arrangement.

9. Concluding Remarks

Proprietary LWC fireproofing has developed and been used extensively over five decades.

Historically plants were regulated by reactive and activity based prescriptive regulations. These were replaced in Australia and Europe with more rigorous performance based regulatory regimes.

Project teams using a prescriptive approach in risk management may not

identify credible fire event scenarios featuring blast and jet fires.

Generally the fireproofing system designs have been developed to meet numerous performance requirements particularly durability and risk based fire scenarios resulting from performance based regulation in Europe, although some inadequate designs are still "grandfathered" in.

Manufacturers of LWC systems have developed the materials and systems to provide fit for purpose SFRM fireproofing arrangements exclusively featuring the profile and solid fill design arrangements that have extensive track record globally and respond predictably and reliably to blast and fire events.

Inherently unsafe boxed PFP designs, though considered obsolete in the oil, gas and petrochemical industries since the 1980's, are still being procured and installed by some operators and contractors.

The designs are being supported by some manufacturers who promote the design with their promotional and technical resources for commercial reasons.

Some operators and the supply chain may not be aware of the negative experience in service of box designs dating back to the 1980's.

Boxed designs performance in service has been shown to be significantly inferior to profile and solid fill designs in terms of durability, corrosion, maintenance and whole life cost.

Boxed designs have been found and shown to respond unpredictably and have poor capability in blast over-pressures and drag forces.

The industry stands to benefit by promoting a greater awareness and application of good practice in fireproofing designs.

So we would suggest that stakeholders in operating, engineering and contracting companies need to be made more aware of the performance requirements particularly durability, corrosion, performance based risk management and response to credible fire scenarios. This could be achieved through the usual mechanisms such as publications, workshops, and guidance. The regulators could also give support and encouragement by emphasising and inherently safer approaches in regulations and guidance.

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7. Control of Major Accident Hazards Regulations 1999 (COMAH)

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Definitions/Abbreviations

API	American Petroleum Institute www.api.org
"Fireproofing"	*The term "Fireproofing" is widely used, although strictly speaking the term is misleading since almost nothing can be made totally safe from the effects of fire exposure for an unlimited time. In effect, fireproofing "buys time" for implementation of other protective systems or response plans such as isolation and use of EIV/ROSOV, unit shutdown, deployment of fire brigades or evacuation. API 2218*
HSE	The Health and Safety Executive (HSE) www.hse.gov.uk
inorganic SFRM	Lightweight Cementitious Fireproofing; a sprayed (or troweled) coating formulated typically from Portland cement and vermiculite or perlite.
LWC	Lightweight Cementitious Fireproofing; a sprayed (or troweled) coating formulated typically from Portland cement and vermiculite or perlite.
PFP	Passive fire protection (PFP) - a barrier, coating or other safeguard which provides protection against the heat from a fire without additional intervention.
RAGAGEP	"Recognized And Generally Accepted Good Engineering Practice" (RAGAGEP) – are engineering, operation, or maintenance activities based on established codes, standards, published technical reports or recommended practices (RP) or a similar document
SFRM	Spray-applied fire resistive materials
stakeholders	Plant operators, design and construction contractors, specialist sub-contractors, suppliers and manufacturers