The Rush to Explosive Clad

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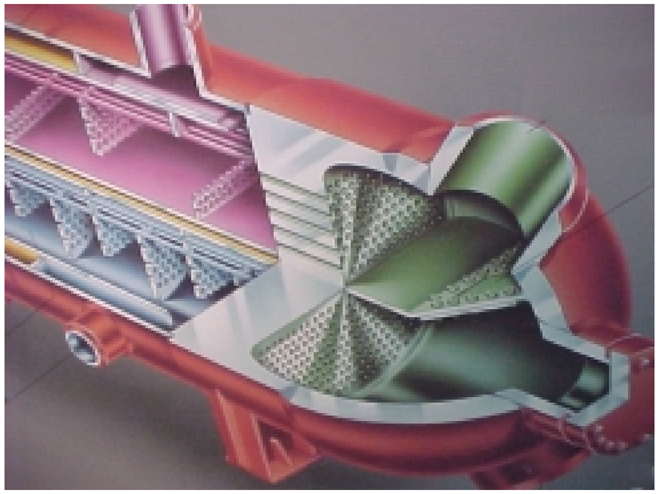
Abstract

The manufacturing and process control steps used to produce explosively bonded clad metal plate are explained through a typical requirement for stainless steel heat exchanger components. Although the story is fictitious the details are daily events at Dynamic Materials Corp. The qualitative explanation gives insight into the well mastered manufacturing process. DMC's sister companies in Europe, Nobelclad, France and NitroMetall, Sweden use similar steps, procedures and quality standards.

It was a cold and foggy autumn day when John Banker's phone rang in Boulder, Colorado. "DMC", the metal man barked into the blower. On the other end was Guy Leaderman, owner of Tubular Exchanger Works in Tulsa, Oklahoma. Known to the heat exchanger industry, customers and employees alike only as "Leaderman". He was in his seventies and out worked and out thought most men half his age. On his desk sits the warning, "Age and treachery succeed over youth and knowledge."

Refinery operators often called Leaderman when they were pressed for fast service. The Gigantic Oil Company, GIOCO, had long owned a northern California refinery. Engineers discovered a problem in the fall maintenance shutdown of the feed effluent heat exchangers in the diesel hydrotreating circuit. When installed twenty-five years ago, the 5% chrome steel construction was adequate for the service. In today's` business environment refineries need the flexibility to process crude oil from different sources. This is called a wide crude slate. Additionally, refineries must meet mandated, cleaner emission standards for the refined motor fuels produced. Hydrotreating is one process used to reduce pollution causing components of gasoline or diesel fuel (gasoil). More aggressive or severe hydrotreating may cause corrosion problems previously unseen. GIOCO inspectors had found severe corrosion during this shutdown. The exchangers were safe, but the refinery had two options. One option was to clean the exchangers and put them back in service. Engineers knew that this would force a costly, unscheduled unit shutdown next summer to replace the heat exchangers. That is unless… new heat exchanger units could be fabricated and installed during the current shutdown. The new heat exchangers would have to be delivered in twelve weeks. US refineries are operated at extremely high utilization rates and down times must be minimized. To accomplish this, heroic efforts would be required by a cast of many, including: engineering company, field contractor, heat exchanger fabricator, tube supplier and explosive bonded clad manufacturer. It just may be possible to have new exchangers installed in the limited time and therefore avoid a very costly additional shutdown. Leaderman received the call.

The new heat exchangers would use 347 grade stainless steel tubes to thwart corrosion. The heads, tube sheets and shell will all be fabricated from explosively bonded, clad manufactured by Dynamic Materials Corp. in the US. The stainless steel is integrally clad to carbon steel or in this case low alloy, chrome-moly "backer" material. This combines the corrosion resistance of the stainless steel with the strength of the backer steel. Chrome-moly grade SA-387 grade 11 is used for high temperature applications.



Heat Exchanger Cutaway Diagram

While Leaderman searched for the tubes, Banker looked for chrome-moly plate and SA240 grade 347 stainless steel needed for the explosively clad components. To meet a five week delivery as Leaderman had requested all of the materials had to be available from stockists. GIOCO and their engineering company had strict material specifications. The alloy steel required “Step Cooled” testing and chemical carbon equivalency requirements. The stainless steel also had requirements for low carbon and corrosion testing. Regardless of the urgency, no short cuts would be allowed by GIOGO. In preparing the bill of material Banker had to take into account all of the thermal cycles the material would see including fabrication and possible future repairs (as specified by GIOCO). This includes simulation tests, numerous stress relief cycles, head forming, plate rolling and in some instances quench and tempering of alloy steels. The stainless steel also had detailed procurement requirements. This review of requirements by DMC occurs before Leaderman receives an order. Once the proper materials are located and prices agreed, orders are issued to Tubular Exchange Works and Dynamic Materials. The clock is ticking. The job site field erector is scheduling cranes for twelve weeks from today. Banker’s team issues the vendor purchase orders and expedites those materials aggressively to meet this schedule.

The first materials required are components for the pressure vessel heads since they require a subsequent hot forming step. Head forming will be performed by a Houston, Texas subcontractor to DMC on an expedited basis requiring two weeks. The heat exchanger shell section will be rolled into a cylinder by Tubular Exchanger Works on their in-house plate rolls. It has to be done below the critical transformation temperature of the steel. Otherwise, quench and tempering steps would be required to duplicate the steel mill’s thermal cycle required for mechanical properties, impact and tensile strength. The tube sheet blank into which the tubes are rolled and welded may be very thick, e.g., 150 mm. The backer material is often a forging and may require prolongation testing.

Prior to handing the order off to the manufacturing group, Banker’s team performs several functions. Included in his staff: Sales Estimators, Engineering Technician/Job Planner, Specification/Order Entry Specialist and Contract Administrator/Order Manager. They have a proven sequence of events mastered over 30 years that must be followed even on a rush job.

<u>Clad Quotation</u>

The first step for the sales estimator is to review all of the engineering documents for pertinent material requirements. A bill of material is compiled. For a rush job, calls are place to selected suppliers to locate metal components. Price and delivery are often quoted by phone and later followed up by fax copy and more often by e-mail. When expedited delivery is to be offered or there are non-standard technical requirements, consultation and approval by DMC engineers and plant load schedulers is required. After electronic document transmittal and a phone conference, the approval of the plant personnel is obtained. Banker extends the tender offer to the fabricator, Tubular Exchanger works, by fax or e-mail.

Leaderman is now less irascible since he knows that Dynamic Materials can supply his heat exchanger clad components with all their special requirements. The schedule is very tight and dedicated trucks, carrying only these materials will be used. DMC's plant is located in Southwestern Pennsylvania, close to mills and stocked inventories of metal. Leaderman issues a purchase order with a late penalty and a bonus clause for early delivery by DMC. Each day counts in dollars. Refinery units generate tens of thousands of dollars per day or cost their owners if they not running.

Order Entry, Job Planning, Order Acknowledgement

DMC uses a software package, Visual Manufacturing™, that produces documents for: order entry, customer acknowledgement, purchase orders, job planning, manufacturing work station instructions, labor hour collection, material use, invoice preparation and accounting functions. It all starts with Banker's seasoned technicians entering the order into the software. A DMC job number is assigned to the customer's order.

The material and sub-contractor purchase orders are written. For the Tubular Exchanger Works order these include: alloy steel backer plate, forgings for the tube sheets and the 347 stainless steel cladder material in two thicknesses. Tube sheet blanks are clad with heavier gauge alloy than are the shell plate and head materials. The extra thickness of stainless steel on the tube sheet blank allows for the machining to final flatness tolerance and a gasket groove around the perimeter. The other products, shell and head plates usually require a minimum thickness in the vessel of 3 mm. It is purchased for explosive bonding purposes greater than the minimum gauge to allow for some thinning in the manufacturing process. The purchase orders are issued. The Contract Administrator will expedite the purchase orders.

The Visual Manufacturing™ program creates manufacturing documents. These include individual workstation instructions and part drawings. These documents are electronically transmitted to the plant scheduler with workstation labor hour tabulations.

The formal, order acknowledgement is also generated. This is reviewed by sales, signed and issued to the customer for their signature and return to DMC. All of the above has taken a few days and metal is in route to the plant in Mt. Braddock, Pennsylvania.

Mt. Braddock Manufacturing Plant Operations

The plant was designed and built by Dynamic Materials as a state of the art explosive clad manufacturing facility. The building is 75,000 sq. ft. including offices and sits on 15 acres of land. Rail tracks run by the property. The plant was commissioned in the fall of 1999. It has functioned near perfectly, as designed, since commencing operations.

New Plant, Mt. Braddock, Pennsylvania, USA

Explosive Bonding Weld Process

The American Welding Society lists two, key process variables for explosive welding: (1) Explosive load and (2) Standoff distance.[i] These "Essential Variables" have been quantified in Visual Manufacturing™. The workstation instructions sometimes called a "Traveler" are published by the software, printed and distributed to the workstations before the metal arrives. Process control of the operations, controlling the essential variables, will have **HOLD POINTS** referenced in the instructions and require appropriate technician, inspector or engineering sign-off. Occasionally, the customer requires a "Manufacturing/Quality Plan" be submitted for information or approval. The engineering and quality staff at the plant prepares this and it is submitted to the customer through the Sales Department Order Manager.

The bonding technology and explosive weld variables are thoroughly described in a recent article by Antoine Nobili, Nobelclad,.[ii]

Plant Operations

The Tubular Exchanger Works order has several identical products since there are multiple, identical heat exchangers being built. The Sales Estimator verified by the Job Planner, groups multiple product items on one assembly of backer and cladder metal combination. This reduces the total number of manufactured "Clad Plates." The individual parts are later cut from the larger plate. This practice maximizes economy of scale.

The manufacturing operations are in four phases: (1) Explosive preparation (2) Prebond, metal preparation (3) Explosive chamber operations (4) Postbond, product processing.

Explosive Preparation

The following are the manufacturing steps followed to prepare the explosive, which is a blasting agent. The main ingredients: raw ammonia nitrate pellets, a distillate oil and an inert ingredient. The last item is used to reduce the explosive's velocity. Detonation velocity is one of the parameters that regulate the system's energy. "Load", an essential variable, is the quantity of the blasting agent that is applied on top of the cladder when set up for detonation. These two variables control the energy applied to the metals, and are somewhat comparable to: voltage, amperage and travel speed in a fusion welding system.

Explosive Preparation

1. Bulk ammonia nitrate is purchased to DMC specification.
2. Distillate oil purchased to DMC specification.
3. Components are mixed to a standard recipe, adding inert diluant to yield a blasting agent with a specific detonation velocity. Various metal combinations and thickness require the explosive to be formulated with different, specific velocities. Mixing is performed in a temperature and humidity controlled building. The particle size and distribution is controlled by specified grinding time and verified by sieve analysis. The density of the batch mixture is measured and recorded. **HOLD POINT**
4. The bulk, blasting agent mixture is weighed, bagged, recorded and identified by batch number and type. It is called ANFO (ammonia nitrate, fuel oil). It is very stable and safe to handle.
5. Explosive velocity for each batch is verified by detonating a sample of the mixture from the batch and electronically measuring and recording the velocity.
6. Upon verification of the velocity, the batch is accepted and certified for production use. **HOLD POINT**
7. Batch serial number and number of bags are entered into a dated inventory log.

Prebond Operations

The Mt. Braddock manufacturing facility has two bays, both bays are served by cranes capable of lifting 45 tonnes (100,000 lb.). In bay one the manufacturing operations performed prior to the explosive operation, Prebond Operations . In bay two the operations that follow the explosive operation are conducted, Postbond Operations.

Prebond Operations

1. Plain materials (metal) may come from DMC inventory or most often from a vendor, mill or stockist.
2. Incoming inspection is performed in both situations controlled by the Workstation Instructions identified by the DMC job number. Bar code stickers are attached to those metals so time and material can be tracked. Metal components are also steel stamped with the job number for traceability to the original vendor documents.
3. Metals are physically inspected for dimensions, surface condition, flatness and any other noted properties.
4. The documents from this inspection go to the Quality Department to be matched with the mill test reports and vendor certification documents. The certification documents are compared and checked for compliance to DMC purchase order and standard material specifications. Once these chemical and physical properties are verified the material is released into production. **HOLD POINT.** Satisfactory completion of all tasks is recorded by the technician, trained in the operation, by scanning the workstation instruction document with the bar code wand.
5. Metal may have to be trimmed, cut or parted.
6. Carbon and low alloy steels require removal of mill scale.
7. Both faying surfaces of the backer and cladder metals are ground on an automatic, gantry, abrasive belt, surface grinder. A specific grind profile is required and is verified by inspection. **HOLD POINT**
8. Frequently, due to standard, available mill sizes for the alloy cladder, fusion seam welding is required to match the cladder to the backer plate size. The backers are never seamed. The seam welding occurs in a “clean room” on an automatic seam welder to DMC procedures qualified to ASME Sect. IX standards. Reference to the appropriate Weld Procedure Specification (WPS) are in the Workstation Instructions for the technician to follow.
9. The welds are all radiographed, interpreted to ASME standards or customer specifications and the weld surface liquid penetrant inspected. **HOLD POINT.**
10. When required by the customer, the cladder plates are heat treated in the thermocouple controlled furnace to stabilize the carbon after the welding operation. This operation may be required by the specifications to maintain the corrosion properties of the alloy. After heat treatment the plate is moved to the grinding operation.
11. The backer and cladder are united at the assembly workstation according to the Workstation Instructions. This is a major operation involving significant, varied detail steps of construction. These steps are key to the explosion bonding process. Technicians build the assembly with close attention to standoff, one of the two main Essential Variables. Standoff is the spacing distance between the two component metals. It is verified with Go/No Go gauge rods. **HOLD POINT**
12. Markings needed by the Explosive Chamber crew are added. The “Assembly” is prepared for a 5-km truck ride to the explosive chamber.

Explosive Chamber Operations

The chamber is an underground, former limestone mine. Large areas were previously mined out resulting in huge chambers. Trucks and cranes drive into the chamber through a portal and tunnel. The chamber has been safely used for thirty years, first by the DuPont Detaclad Division prior to that business being acquired by DMC in 1996. It is proven reliable.

Front Chamber Entrance

Rear Portal, Ventilation Equipment

Explosive Chamber Operations

1. On a daily basis, flatbed trucks deliver the prepared assemblies to the pictured site.
2. Several assemblies are set up and exploded simultaneously. The mine requires several hours to ventilate dust. Multiple explosive shots can be detonated within a 24 hour period giving high throughput capacity.
3. The trucks and cranes are driven into the chamber and the assemblies are placed on a sand bed on the chamber floor according to written procedures. The equipment is evacuated.
4. Some backer metals require preheating. Flame burners are used and thermal crayons are used to verify the temperature.
5. Precut, fiber board framing is attached to the assembly according to the workstation drawings. The light framework holds the level bed of granular ANFO. The instructions list the specific batch serial number and number of bags. These have been drawn from the inventory and moved into the chamber with the assemblies. The bags are opened and poured directly onto the cladder plate.
6. The balance of the crew is evacuated and two technicians apply the high explosive booster charge, detonation cord and electric blasting cap. All of the assemblies are safely fired, simultaneously from outside the mine. Use of the chamber allows operations in all weather.
7. The mine and chamber are ventilated. After the dust has settled the next shift picks up the clad plates and transports them back to the plant. Markings including the job number are reapplied for easy visibility. The steel stamp identification is permanent throughout the operation.

Post Bond Operations

1. After cladding, some metals first go to the heat treat furnace for stress relief.
2. Some plates go to a flattening operation on either a roller leveler or a press.
3. Automatic ultrasonic straight beam evaluation of the metallurgical bond is performed on the entire plate. Printed copy record is reviewed by the Quality Deptartment **HOLD POINT.**
4. Individual, purchase order parts are cut by an automatically controlled, gantry flame torch.
5. Test bars are cut and specimens are machined for mechanical tests. The Quality Deptartment performs the mechanical testing in house and certifies the results. **HOLD POINT.**
6. Final flattening operation of all tube sheet blanks (TSB) and most plate sold to ASME flatness requirements is performed.
7. Vertical boring mill machining of the TSB's edge and face is performed as required.
8. Final inspection: dimensions, flatness, liquid penetrant test of cladder seam welds. Positive Material Identification (PMI) can be performed for alloy chemical analysis if required.
9. Document review by the Quality Deptartment **HOLD POINT**
10. Parts that require subcontractor final processing, i.e., heads, rolled cylinders, sawed parts are shipped with a partial set of quality documents. The complete package is completed after the operations are certified.
11. The products that are completed at DMC usually receive a final surface preparation such as grit blasting. The part then moves to the shipping area.
12. The crating is carried out in accordance with DMC specifications or customer requirements. All shipments to the customer are required to contain the complete Quality Deptartment certified document package. This is the final **HOLD POINT** for parts completed at DMC.
13. Subcontractor completed items are some times inspected by a DMC contracted third party inspector but more frequently final inspection is performed by the contractor and certified. The DMC Quality Department reviews furnace records, UT reports and physical dimensions and testing. Final shipment from the contractor requires written release by DMC. **HOLD POINT**

Tensile Testing

All measuring and inspection equipment is calibrated and certified by an outside agency on a periodic basis as required by the DMC Quality Program. This includes electric furnace controllers, testing tools, flatness grids, measuring devices.

The heads, tube sheet blanks and shell sections were shipped by DMC in time for Tubular Exchanger Works to complete units and get them on site just in time.

It was warm and sunny day when Banker's phone rattled to life. It was Leaderman calling to say that he had hung another letter of congratulations on his lobby wall. GIOCO had sent him a plaque and a letter of appreciation and Leaderman was calling to pass the appreciation on to Dynamic Materials.

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[i] . Welding Handbook, pub. American Welding Society, Vol.3, 8th ed., pp 765-781.

ii. **Nobili, Antoine**, "The Safety Clads", *Stainless Steel World*, January/February 1998, pp 33-37

About the author
Mr. Young, Houston , TX is Marketing Manager with Dynamic Materials. He has 30 year's experience in welding and fabrication, the last 13 with DMC in various positions including plant manager. He holds a degree in metallurgical engineering. www.gyoung@dynamicmaterials.com

Explosive Cladding Technology General References

1. **Sharp, W.F.,** "The Explosion Cladding Process", *Engineering Design*, Sept./Oct. 1979.

2. **Pocalyko, A.,** "Explosively Clad Metals", Encyclopedia of Chemical Technology, Vol. 15, 3rd ed., John Wiley, New York, pp 275-296 (1981)

3. **Banker, J.G.**, **Reineke, E.G.**, "Explosion Welding", ASM Handbook, Vol. 6, "Welding Brazing, and Soldering", Vol.6, ASM International, Materials Park, OH, pp. 303-30 (1993).

4. **Linse, V.D.**, "Procedure Development and Process Considerations for Explosion Welding", ASM Handbook, Vol. 6, "Welding Brazing, and Soldering", ASM International, Materials Park, OH, pp 896-900 (1993).

5. **Nobili, A.**, "Explosion Bonding Process", NOBELCLAD TECHNICAL Bulletin NT200, Rivesaltes Plant, France

6. **Nobili, A.,** NOBELCLAD, et al., "Recent Developments in Characterization of a Titanium-Steel Bond Interface", Proceedings of Reactive Metals in Corrosive Applications Conference, Wah Chang, Albany, OR, Sept. 1999, pp. 89-98.

7. **Patterson, A.R.**, "Fundamentals of Explosion Welding", ASM Handbook, Vol. 6, "Welding , Brazing, and Soldering", Vol.6, ASM International, Materials Park, OH, pp.160-64 (1993).

8. **Blazynski, T.Z.**, Explosion Welding, Forming and Compaction, 1983, Applied Science Publishers, ISBN 0-85334-166-4.

9. **Crossland, B.**, Explosive Welding of Metals and its Application, 1982, Clarendon Press, ISBN 0-19-859-119-5.

10. **Ezra, A.A.**, Principals and Practice of Explosive Metalworking, 1983, Industrial Newspapers Limited, ISBN 0-90199405-7.