

Engineering Procedure

SAEP-355

29 February, 2004

Field Metallography and Hardness Testing

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1 Scope

This procedure provides Saudi Aramco guidelines for performing satisfactory surface replication for the purposes of in-situ metallographic examination or field metallography and hardness testing on carbon and low-alloy steel plant equipment and in-plant piping. The procedure is designed to reveal general microstructural features such as those observed in new or aged metallic components; it is also tailored to help the metallurgical engineer in the identification/categorization of surface-breaking defects and flaws of fabrication or service-induced origin. The procedure is also suitable for the assessment of high temperature equipment operating in the creep domain. Replicas produced in accordance with this procedure will be acceptable to ASTM E1351-01 (Production and Evaluation of Field Metallographic Replicas).

Important Requirements

- It is noted that no company or industry certification is currently available to qualify engineers/technicians to this procedure, i.e., for both field metallography and hardness. CSD technicians are however adequately trained to follow the guidelines laid herein.
- Proponents requiring the undertaking of field metallography and hardness testing may, in the first instance, request this service from the Materials Engineering Unit of CSD. Alternatively, outside contractors may be utilized, subject to a qualification test by CSD and satisfactory compliance with this procedure.

2 Conflicts and Deviations

- 2.1 Hardness testing carried out by TeleBrinell (hammer) as per other Standards, e.g., [SAES-W-010](#) [Welding Requirements for Pressure Vessels] and NACE Standard RP0472 [Methods and Controls to Prevent In-Service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments], remain unaffected. Hardness testing based on these standards, i.e., [SAES-W-010](#) and NACE RP0472 does not constitute a deviation from this procedure. The hardness procedure laid out in this document requires a high level of surface preparation and is only applicable when undertaken in conjunction with field metallography.
- 2.2 Any conflicts between this Procedure and other applicable Saudi Aramco Engineering Procedures (SAEPs), Saudi Aramco Engineering Standards (SAESs), Saudi Aramco Materials System Specifications (SAMSSs), Saudi Aramco Standard Drawings (SASDs), or industry standards, codes, and forms shall be resolved in writing by the Company or Buyer Representative through the Manager, Consulting Services Department of Saudi Aramco, Dhahran.

- 2.3 Direct all requests to deviate from this Procedure in writing to the Company or Buyer Representative, who shall follow internal company procedure SAEP-302 and forward such requests to the Manager, Consulting Services Department of Saudi Aramco, Dhahran.
- 2.4 This procedure is the property of Saudi Aramco. When replication services cannot be provided by CSD to proponents and a contractor has to be used, this contractor shall submit his own procedure for qualification by CSD.

3 References

The requirements contained in the following documents apply to the extent specified in this procedure.

3.1 Saudi Aramco References

Saudi Aramco Engineering Procedure

[SAEP-325](#)

Inspection Requirements for Pressurized Equipment

Saudi Aramco Engineering Standard

[SAES-W-010](#)

Welding Requirements for Pressure Vessels

3.2 Industry Codes and Standards

American Society of Testing of Materials

ASTM E1351-01

Production and Evaluation of Field Metallographic Replicas

ASTM A956-02

Standard Test Method for Leeb Hardness Testing of Steel Products

National Association of Corrosion Engineers

NACE RP0472

Methods and Controls to Prevent In-Service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments

4 Definitions and Abbreviations

CSD: Consulting Services Department.

MEU: Materials Engineering Unit.

ME&CCD: Materials Engineering and Corrosion Control Division.

CSD Engineer: Metallurgical or Mechanical Engineer working in the Materials Engineering Unit of CSD.

CSD or Metallurgical Technician: Technician working in the Metallurgical Laboratory of CSD and trained in field metallography and hardness testing.

Replication: A form of Field Metallography, in which a replica image of the material microstructure is made.

HAZ: Heat-Affected Zone.

Proponent: Plant engineer, supervisor or manager for whom the work is being carried out.

UCI: Ultrasonic Contact Impedance, a method that uses a diamond pyramid indenter to leave an impression on the test surface. The indentation area is electronically detected by measuring the shift of an ultrasonic frequency.

Leeb Hardness Test: A dynamic hardness test method using a calibrated instrument that impacts a spherically shaped ball or diamond tipped body with a fixed velocity (generated by a spring force) onto a surface of the material under test. The ratio of the rebound velocity to the impact velocity of the impact body is a measure of the hardness of the material under test.

5 Health and Safety

This procedure involves grinding, use of chemicals and often work in confined spaces or at heights. Care shall be exercised at all times to ensure personnel safety is not at risk. In particular, the following shall be obeyed:

- Health and Safety datasheets (or MSDS sheets) shall be obtained and complied with by the CSD Engineer and Technician for all chemicals (solvents and etchants) in use by the CSD Technician.
- All personnel shall be familiar with the local site safety regulations; these shall include knowledge of the emergency alarms, muster points, evacuation procedures local warnings, etc.
- All accidents and incidents (near misses or dangerous occurrences) shall be reported to the local safety engineer.
- All replication work shall be carried out in well-ventilated work areas.

- Local site regulations shall be obeyed.
- Adequate personal protection equipment shall be worn at all times when grinding, polishing, etching and replicating, as follows:
 - Clothing – Full coverall boiler suits for general site conditions or dust suits, as dictated by working environment
 - Safety hat or helmet
 - Safety footwear, i.e., with steel insert toe protectors which must not be exposed or conducive to sparking
 - Safety goggles when profiling/coarse grinding and flapping or safety spectacles when fine grinding/polishing
 - Hearing protection (muffs or ear plugs)
 - Gloves
 - Correct type respirators in environments where potential breathing hazards have been identified
- When taking replicas in equipment fired with vanadium-containing fuel oils, e.g., boilers and heaters, adequate respiratory protection shall be worn to avoid exposure to vanadium dust. It is the responsibility of the proponent's safety engineer/coordinator or work permit issuer to declare the equipment safe for entry after the appropriate checks have been carried out on the internal atmosphere of the equipment.
- Work must not commence prior to obtaining a hot work permit by an approved Saudi Aramco hot work permit receiver.
- Work must not be carried outside the validity of issued work permits. If required, an extension to the work permit must be sought from the proponent's issuer.
- Chemicals – Field metallography involves use of chemicals such as acetone, methanol, ethanol, hydrochloric, picric and nitric acids. Other chemicals may also be used depending on the material type under investigation.
 - Where practical, every effort should be made to arrange for either provision of chemicals by the proponent's chemical laboratories or local supplier. This situation is sometimes unavoidable for distant areas, i.e., requiring air travel, e.g., Yanbu, Jeddah, Rabigh, Shaybah, etc., due to Aramco Aviation and other airline restrictions.

- If transportation of chemicals by car is unavoidable, then adequate precautions against accidental breakage/spillage will be required. In small quantities, i.e., total <5 liters, chemicals shall be carried in glass "Winchesters" inside properly labeled plastic transport containers, inside a secure metal box. When chemicals are required in large quantities, i.e., total >5 liters, these shall be carried in the original supplier's container and packaging.
- Preparation of chemicals, i.e., filling, mixing, etc., should be carried out in a fume cupboard or a well-ventilated area.
- Rubber/PVC gauntlet gloves and safety goggles must be worn when handling chemicals. The use of a barrier cream is recommended on areas of unprotected skin.
- Disposal of unwanted/left-over chemicals must not be carried out without prior-consultation with the Supervisor of the proponent's chemical laboratory. In some cases, regulated disposal procedures are required. In all cases, the local disposal procedures must be followed.
- Electrical equipment must not be tampered with; any modification, maintenance, repair or connection to local facility's supply must be carried out by the proponent's electrical technician. Under no circumstances should the CSD engineer or technician engage in electrical-related maintenance work.
- To avoid damage to CSD's field metallography electrical equipment and facility's electrical supply system, the CSD engineer or technician must advise the proponent's electrical technician about CSD's requirements for appropriate voltage and power consumption, i.e., 110 or 220 volts, 1 kVA.
- When performing rough grinding, the CSD engineer or technician must ensure that the chemical-containing plastic bottles are adequately protected from the sparks emitted by the grinding action. These bottles must either be placed in an aluminum storage box or in an appropriately declared safe area.
- Equally, care must be taken regarding the disposal of used solvent-impregnated cotton wool swabs. These must be placed in a plastic garbage bag. Inadequate measures can result in fire hazards to equipment and adjacent personnel.
- It is the responsibility of the CSD engineer or technician to maintain a clean working area during the field metallography process and ensure that all "rubbish" is adequately disposed of at the end of the day or shift.

6 Technical Procedures

6.1 Field Metallography

A flow diagram outlining the field metallography procedure is shown in Figure 1.

6.1.1 Equipment

A checklist of equipment normally required to perform field metallography is given in Appendix A.

6.1.1.1 Rough/Fine Grinding

Grinding shall be carried out using electric or compressed air-driven, hand held, angle grinders, in-line grinders and fine grinding/polishing machines (e.g., Struers Transpol) approved by Saudi Aramco. Successive stages of preparation normally require fiber-reinforced abrasive discs, 80 and 180 grit flap wheels; and P120, P220, P400 and P800 grinding discs/papers. Note that there is a marked difference between European and USA grit-grading number, at the finer grit sized (P800 European is equal to 400 grit, USA).

6.1.1.2 Polishing

Polishing shall be carried out using portable polishing machines acceptable to Saudi Aramco. Successive stages of polishing require 14-micron diamond paste on Dur cloths (optional), 6-micron diamond paste on Mol cloths and 1 micron diamond paste on Nap cloths. A lapping lubricant is to be applied by aerosol, waste bottle or trigger spray. Suitable suppliers for these consumables are:

- Grinding discs P50, P120, P220, P400 Struers (Tradi)
- Grinding papers P800 (PSA backed) Buehler
- Mol cloths Struers (Tramo)
- Nap cloths Struers (Trapp)
- Dur cloths Struers
- Diamond Paste Engis Ltd (Hyprez)
- Lapping lubricant Engis (Hyprez)

6.1.1.3 Etchant

This is usually applied from a wash bottle, trigger spray (preferred) or by using a cotton wool swab. Typically, the etchant used for low-alloy ferritic steel is 2% Nital (nitric acid in alcohol). If swab etching is used, care should be taken so as to avoid scratching the polished replication area.

6.1.1.4 Solvent

A suitable solvent shall be used as a cleaning wash for removing debris and etchant. Suitable solvents include acetone, methanol and ethanol. Due to minor health risks associated with using solvents, a suitable hand barrier cream shall be used according to the manufacturers' instructions. When performing polishing with diamond paste, it may be necessary to use acetone as a final wash if difficulty is experienced with the slow evaporation rate of methanol or ethanol.

Industrial Methylated Spirits (IMS) may be used during grinding and polishing stages but should not be used during etching and replication stages to avoid staining.

Acetone shall be used for replication purposes. Ethyl acetate will be used in circumstances where higher ambient temperatures (up to 60°C surface temperature) render the use of acetone inappropriate.

Solvents shall be applied from a wash bottle or trigger spray.

6.1.1.5 Replication Material

Cellulose acetate film, thickness approximately 35 micron (0.0014 inch) shall be used for replication. Suitable replication material is that supplied by Agar Scientific Ltd (part No. G255).

6.1.2 Procedure

6.1.2.1 General Grinding/Polishing

The various stages of grinding/polishing/etching/replication are described below. A flow diagram for the Saudi Aramco procedure is shown in Figure 1.

Each subsequent stage of grinding/polishing shall be carried out at approximately 90° to the previous stage. This will allow any remaining scratches from the previous stage to be observed. Certain situations when access is poor will dictate that when using flap wheels the full 90° displacement cannot be achieved. Each stage shall be performed until all previous scratches and inter-stage etching is removed beyond doubt. This may be achieved by visual examination of the replica site for complete removal of all scratches and then continuing the grinding/polishing stage for a similar time. Excessive force on the polishing tools shall be avoided. This will reduce any surface deformation.

6.1.2.2 Cross-Weld Replicas

The site prepared for replication, i.e., fully polished, shall be approximately 25 mm wide and extend for approximately 20 mm from the weld toe into the base material. Figure 2 shows a typical replica site outline. Replicas shall include 1st base material/1st HAZ)/weld metal/2nd HAZ/2nd base material.

6.1.2.3 Surface Profiling

Surface profiling by rough grinding is initially carried out to provide a smooth, but not necessarily flat area. This operation also permits the necessary elimination of surface effects such as oxidation and corrosion. For other surface effects such as carburization and decarburization, the CSD engineer must be consulted to advise on the requirements to eliminate these factors; one prime consideration regarding these effects is the depth or penetration and accordingly specialist advice is required so as not to compromise the integrity of the equipment under investigation. On thick-section welded components, the surface profiling will require removal of approximately 1 to 1½ mm from the weld toe. However, on thinner components, the overall thickness shall not be reduced by more than approximately 5%. Extreme care should be exercised when surface profiling thin-walled tubing, e.g., process, boiler or steam superheater tubes. If in doubt, the CSD engineer must be consulted.

6.1.2.4 Rough Grinding (Flapping)

Coarse grinding marks shall be removed using 80-grit followed by 180-grit flap wheels. Where component geometry does not allow use of flap wheels, initial preparation shall use P50 grinding discs followed by P120 grinding discs. The subsequent stage shall be a very heavy etch followed by another P120 grinding. This latter stage is very important to remove deformed material and shall be carried out at 90° to the previous P120 disc or 180-grit flap wheel stage.

6.1.2.5 Inter-Stage Etching

Etching shall be performed using the etchant and equipment described in Section 6.1.1.

Inter-stage etching shall be carried out between the stages of fine grinding and polishing. To assist in an even material removal, this shall be a heavy etch followed by a solvent wash. This wash shall remove all previous grit and debris from the replica site. The etch period is dependent on the material composition, condition and ambient temperature. This period shall be determined from experience and should result in clearly visible HAZs. The duration is typically 10-30 seconds and shall be confirmed by the CSD engineer or technician.

6.1.2.6 Fine Grinding

Subsequent stages of replica site preparation shall be carried out using P220, P400 and P800 grinding discs or papers.

Each stage shall be followed by an inter-stage etch as described in Section 6.1.2.5.

6.1.2.7 Polishing

Final stages of replica preparation shall be carried out using 6 micron and 1 micron diamond pastes. An optional stage of 14-micron diamond paste may be required at the discretion of the CSD engineer or technician. The 1-micron stage shall be repeated at least once. The final 1-micron polish shall be performed such that the cutting direction is perpendicular to the weld interface; this is to reduce contamination scratches.

6.1.2.8 Cleaning of Polished Replica Site

Prior to surface examination, the replica site shall be carefully cleaned with a solvent wash followed by a solvent-soaked (cotton wool) swab. Several swab wipes will be required to achieve an adequately cleaned surface. After each wipe, the swab shall be discarded and a new one used for the next wipe. Wipes shall be carried out gently and start at the center of the replica site to avoid contamination and scratching.

6.1.2.9 Replication/Etching

Precautions shall be taken to ensure contamination of the replication film with dust, skin oils and etchants is minimized.

At least three replicas shall be taken at different levels of etching; the first replica site etch shall be "light". Under good lighting, the microstructural variation shall be just apparent. The etchant shall be applied as an even wash for an appropriate duration; generally 5-10 seconds. The etchant shall be thoroughly and evenly removed by a solvent wash.

6.1.2.9.1 Replica Application

Replicas shall be made by applying an Acetone wash to the etched replica site and quickly, but carefully, laying on the cellulose acetate film. Surface tension will cause the film to be pulled down onto the replica site. Bubbles in the replica shall be avoided when laying the film on the site, by starting from one edge. For difficult geometries, light finger pressure may be required to ensure adequate contact of replica to surface.

6.1.2.9.2 Replica Removal and Storage

Replicas shall be left in place until they are no longer soft and are easily removed. Ambient conditions will determine the time required before removal. Typically, a period of 5-10 minutes is required. Identification labels (described in Section 5) shall be attached to the non-contact (wrong) side of replicas before removing.

Replicas shall be removed by carefully peeling them from the replica site to avoid tearing. Replicas shall then immediately be placed flat in clean, re-sealable, plastic bags. Identification labels shall remain securely attached to replicas. Replicas shall be stored flat between the pages of a hard-covered book. Alternatively, the replicas may be mounted on glass slides as per ASTM E1351.

6.1.2.9.3 Successive Replication

At least two further replicas shall be made with "medium" and "heavy" etches. After removal of the first replica, a "medium" etch shall be made by repeating the procedure described above on top of the first "light" etch (typically, an additional 5-10 seconds etching time for each stage). The microstructural variation across the weld interface shall be clearly visible under good lighting. A "medium" replica shall then be made. The procedure is then repeated to produce a "heavy" etch.

Under certain circumstances, it may be necessary to make a fourth "very heavily" etched replica, if the final etch above does not appear to be sufficient. The "very heavy" replica shall be in addition to, and not replace the "heavy" replica.

In unusual circumstances, it may be considered necessary to repeat replication at a given level of etch, e.g., when replica is partly torn on removal, but otherwise good. A repeat replica is acceptable providing it is clearly identified as "repeat" by the CSD Technician.

6.1.2.9.4 Recording

Replicas shall be identified with a self-adhesive labels approximately 12mm x 38mm. These labels shall be attached to the non-contact side of the replica prior to its removal from the component.

Labels shall include the following information:

- Component e.g., Platformer Reactor PV-1
- Weldment e.g., Outlet Nozzle
- Location e.g., West Position
- Orientation e.g., Head-Nozzle
- Personnel Replica No. e.g., Ali Y. Al-Kawaie 7
- Etch Stage e.g., Medium

Suitable abbreviation shall be agreed with the CSD engineer such that the actual replica label would be:

Plat. React.	Head	AYK7
Outlet Noz.		
West	Nozzle	M

All replica details shall be entered in a CSD site record book. Each technician shall start a new book for each site visit or project. Replicas shall be given a unique and sequential number. An example of an adequate site record entry is given in Figure 3.

6.1.3 Replication Hints

- Grinding – It is important to remove all traces of oxide/corrosion products from the site being prepared for replication. However, extreme care should be exercised when dealing with thin section components so that not too much material is removed.
- Flapping – As with grinding, it is important not to remove too much material on thin section components, i.e., do not attempt to remove all scratches from a tight corner; use 50 grit paper instead. Although it is stated in this procedure that the 80 and 180 stages should be carried out at 90° to each other (Section. 6.1.2.4), in practice this is not always possible. In this case, offsetting the orientation slightly is considered acceptable.

- Fine grinding papers wear out very quickly. It is important not to waste time trying to polish with a worn out paper; this can lead to work hardening effect. It usually takes anything from 3 to 10 papers per site depending on replica site size.
- When performing the 6 and 1-micron polishes, it is essential to make sure that the pads are clean before commencing the polishing process. The pad can be cleaned by using the freshly removed backing paper and gently sweeping away all traces of dirt or contaminants.
- The amount of diamond paste must be kept to a minimum. The paste may be impregnated into the pad by pressing it onto the clean surface about to be polished. This obviously should be done before switching on the polishing tool.
- Replicating – Speed is the key to this process. Acetone tends to evaporate very quickly; it is therefore important that the entire replication site is wetted.

6.2 Hardness Testing

The hardness testing requirements described in this procedure are solely applicable when performed in conjunction with metallographic replication. . As indicated in Section 2.1, hardness testing carried out by TeleBrinell (hammer) as per other Standards, e.g., [SAES-W-010](#) [Welding Requirements for Pressure Vessels] or NACE Standard RP0472 [Methods and Controls to Prevent In-Service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments], remain unaffected. Test methods conducted with other devices on lower-quality surface finish, e.g., grinding only, are not covered in this procedure.

The hardness procedure laid out in this document requires a high level of surface preparation, i.e., 1-micron polish, leading to reliable results.

6.2.1 Equipment

Hardness testing is usually carried out using portable devices. The equipment currently used by CSD is the Krautkramer's MicroDur 10, better known as MIC-10 hardness tester. This device is based on the UCI (Ultrasonic Contact Impedance) method and uses a diamond pyramid indenter to leave an impression on the test surface. The indent is then sized using ultrasonic methods to yield a hardness value in Brinell, Vickers or Rockwell C Numbers. This tester has the capability

to continuously average the measurements being taken and has proven to provide reliable results on replica-type surface finishes.

Another reliable portable field hardness tester in use within Saudi Aramco is the TeleBrinell. This apparatus is based on a comparative method. Essentially, the comparative tester is struck with a hammer that produces an impression on the equipment/pipe surface and a reference bar with a known hardness. The impression diameter on the reference bar and equipment/pipe surface are determined with a microscope and compared to determine the equipment/pipe hardness. Reference bar hardness should be selected to be similar to the test piece. Since the hammer type Brinell tester is based on a comparison of hardness impression on a known and unknown material, it is a self-calibrating method.

Some specific considerations applied to this device and similar portable hardness testers are:

- Hammer impact type would be difficult to use in limited access areas or in all positions
- A large remaining impression may not be suitable for all applications
- According to manufacturer, the minimum wall thickness for hammer impact testers that depend on a reference bar comparison is about $\frac{3}{16}$ inch (5 mm). However, if any test piece deflection results from the test, such a comparison would be invalid.

It is cautioned that, since a hammer blow is used with this device, extreme must be taken when testing service-embrittled equipment such as steam reformer heater tubing and heavily carburized material as the component under test may either crack or shatter. In all cases, the CSD engineer should be consulted to provide further guidance on the use of this device on suspect components.

Important Note:

Rebound or Leeb portable hardness testers utilizing spring-loaded probes, e.g., Proceq Equotip, are not permitted for use on Saudi Aramco equipment/piping due to their unreliability.

6.2.2 Hardness Measurement

This section refers to hardness measurement using the Krautkramer's MicroDur 10, better known as MIC-10 hardness tester or similar devices.

On completion of all replication, hardness measurements are required from each replica site, i.e., base material or from both base materials and weld metal for cross-weld locations.

The CSD Technician shall at first perform tests on the supplied (with the instrument) calibration block to check the accuracy of the apparatus; five measurements are sufficient for this operation and all results shall be recorded.

At least 20 readings shall be taken on the as-polished surface, i.e., 3 times 20 (60 readings) for cross-weld locations. Experience has shown this to be a statistically representative sample in view of the variability in portable hardness testing equipment and inhomogeneity in the material. For weldments, as indicated above, each area, i.e., each base material and weld metal shall be tested separately ensuring that each set of hardness data is identified and traceable.

For the assessment of the suitability of repair or production welds for the avoidance of environmentally induced damage, the reader is requested to follow the instructions given in [SAEP-325](#) and [SAES-W-010](#), as appropriate. These documents describe the location, number of tests required and provide acceptance limits for hardness.

7 Responsibilities and Requirements

- 7.1 Unless instructed otherwise by the proponent, the CSD Engineer shall be responsible for the selection of base material/weldment location targeted for examination by the replica technique and hardness testing. He shall also be responsible for the interpretation of the replicated microstructure / defects and relevant hardness measurements.
- 7.2 The CSD Technician shall be responsible for producing good quality and interpretable replicas and their filing at the CSD metallurgical laboratory. He shall also be responsible for performing adequate hardness measurement and reporting representative results.
- 7.3 The proponent shall be responsible for the provision of the following:
 - Plant access and security clearance
 - Details of plant safety regulations and requirements for any safety briefing or qualification prior to work start
 - Suitable access, scaffolding, ventilation and lighting at all workscope components

- Power supply to all workscope locations
- Preparatory grinding or sandblasting as required prior to the field metallography work
- Assistance with general inspection work
- Office accommodation
- Chemical laboratory support and provision / disposal of chemicals, as required.

8 Plant Assessment and Material Identification Subcommittee

Mohammed Al-Anezi	Chairman
Abdelhak Kermad	Coordinator / Author
Mark Moore	Member
Nasser Balhareth	Member
Olavo Dias	Member
Salamah Al-Anizi	Member
Moraya Al-Gahtani	Member

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Figure 1: Replica Procedure Flow Diagram

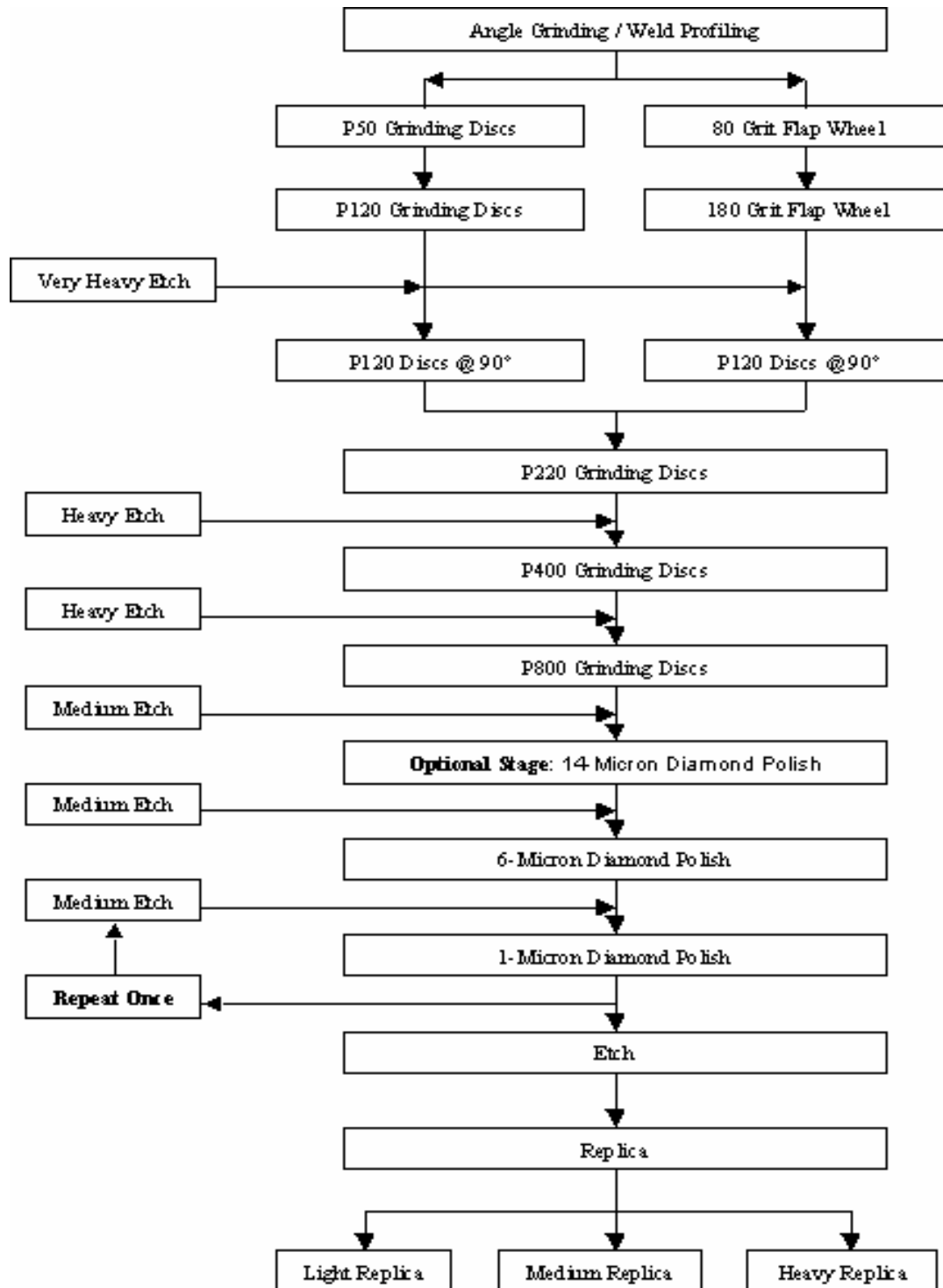


Figure 2: Typical Replica Outline

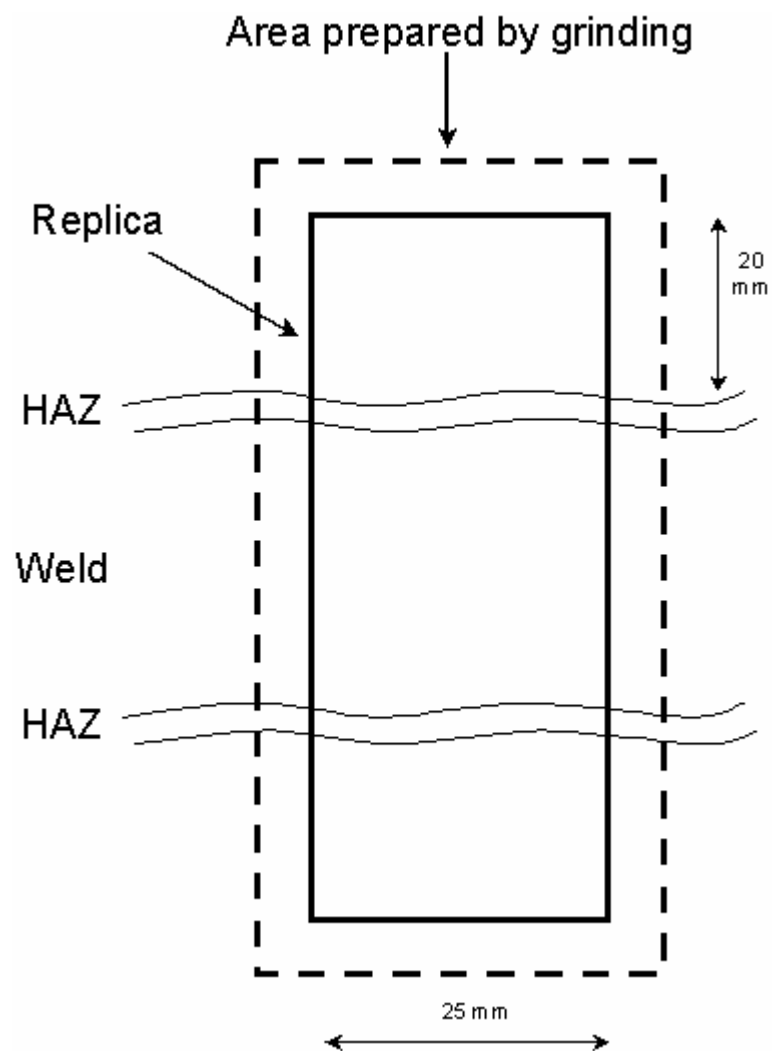
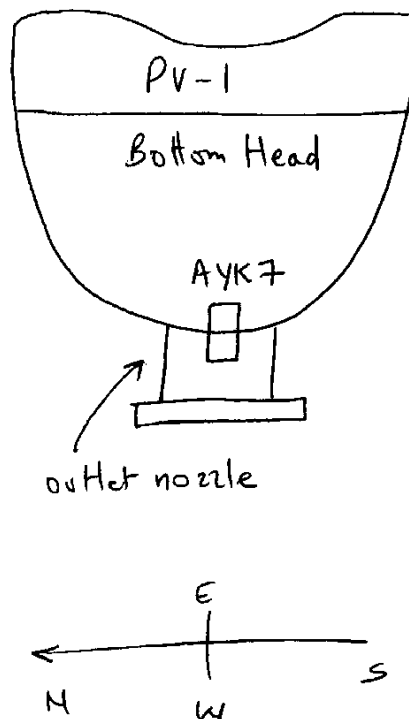


Figure 3: Example Replica Site Record Page

Site Replication Sheet	
Date: 5/31/03	Replica No.: AYK7
Plant: Riyadh Refinery	
Component: Platformer Reactor PV-1	
Description of Area Replicated: Outlet Nozzle. Head/Nozzle Weld West position	Sketch: 
Etch Details: Nital Light Medium Heavy	
Other Comments:	

Appendix A – Replication Equipment Checklist

1. Angle grinder (+ wrench or spanner)
2. Flapper grinder or rubber disc for grinding paper
3. Polishing machine
4. Extension lead
5. Tools/Spares
6. Replication box
7. Personal safety gear (shoes, hat, glasses, goggles, gloves, ear plugs, dust masks, etc.)
8. Flashlight and spare batteries
9. Replication material (acetate)
10. Small plastic bags
11. Adhesive labels
12. 6 micron diamond paste
13. 1 micron diamond paste
14. Mol polishing cloths
15. Nap polishing cloths
16. P50, 120 grinding discs or flap wheels
17. P220, 400, 800 discs or papers for polishing
18. Diamond polishing lubricant
19. Cotton wool
20. Methanol/Ethanol (cannot air-transport)
21. Etchant (cannot air-transport)
22. Spray/wash bottles
23. Pens/notebooks
24. Hard cover book for replica storage/transport
25. Measuring cylinder for etchant
26. Funnel