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EMERGENCY REPAIR TECHNIQUES

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EMERGENCY REPAIR TECHNIQUES

1. INTRODUCTION

During the last decade plants, especially in the process industries, have grown considerably in size and have been based increasingly on single stream units. At the same time the practice of installed spares has been drastically curtailed. As a result, the effect of breakdown of equipment for whatever reason has become increasingly serious and the cost of downtime has increased considerably. As a consequence, there has been a growing demand for emergency repair techniques and engineers have been prepared to consider new methods and materials as means of achieving results. The prime objective of such a repair is to keep a unit in operation either without shutting down at all or with the very minimum of downtime until a permanent repair by conventional means is achieved or replacement equipment fitted at a time convenient to the operation of the plant.

The knowhow developed as a consequence of this situation has made possible, at least on a temporary basis, the repair of a wide range of defective equipment which at one time would have been automatically scrapped. Furthermore, many of the repairs done on an emergency basis are proving effective in the long term and the method a most useful tool to hard pressed maintenance engineers. The repairs range from the simple sealing of holes in tanks to the build-up of damaged parts of highly sophisticated machinery.

Although the interest in the development of these techniques has been created by the demands of operators of large scale plant working on a continuous basis, the knowledge gained can be applied over a much wider field. The methods used are very cheap and relatively simple and, therefore, must be of use in plants operated on a very modest scale. Developing countries using imported equipment may have delivery problems with spare parts and therefore, may be faced with difficulties in keeping plants, large and small, operational. In these situations the methods described should be particularly attractive, especially in view of the low cost involved, the simple equipment required, and the satisfactory results, which can be attained without the use of highly skilled labour.

2. REPAIR TECHNIQUES

The techniques discussed in this paper are based on the use of synthetic resins, rubbers and sodium silicate. The omission of methods such as welding, metal spraying and metal stitching is deliberate and is not meant to imply that these techniques do not have an important role in the emergency repair of plant. Later in the paper, comparison is occasionally made with such alternatives and, in some cases, the techniques are complementary. There is obviously a large number of cases where more conventional methods will still be preferred. For example, a leaking tank should be welded if it is in a situation where there are no fire restrictions and where the level in the tank can be temporarily lowered below the level of the leak. The only case for an alternative method is if the welding facilities are not available on site.

3. REPAIRS USING SYNTHETIC RESINS

3.1 Materials

The possibilities of using synthetic resins arise from the properties of certain families of materials. Basically, the requirement is a resinous material which will normally be in the form of a syrupy liquid and be stable in this condition at ambient temperatures although fairly small changes in temperature may have quite a marked effect on the viscosity of that liquid. It must be possible to polymerise the resin into a tough strong mass by the addition of other chemicals classified as "catalysts", "hardeners" and "accelerators". The setting process of such a resin is a chemical reaction which passes through recognisable stages from initial set to final cure. Initial set is recognised by the development of a condition in which the resin is no longer fluid but is sufficiently plastic to be readily deformed. Final cure means that the reaction is complete and the properties of the solidified material have been fully developed.

Arising from these basic properties there are a number of cautions which must be observed in practice. As in many other chemical reactions, heat is developed as setting proceeds. Applied heat will always accelerate the reaction just as low temperature will retard it. Generally, there is a critical temperature below which the reaction will not proceed at all. The actual temperature varies with the resin and the particular hardener system, but most systems become difficult below 5°C. As a general rule there is a limit to the amount of heat which can be applied. Too much heat may cause a resin to flash set or to foam.

Because the reactions are exothermic, care has to be exercised when selecting a system for mixing large quantities. Some systems cannot be controlled when mixed in bulk. Another way in which the rate of the reaction can be varied is by adjusting the quantities of chemicals mixed. This control is often used to counteract the effect of mixing in bulk or of high or low ambient temperatures. It is also important that the selected hardeners, accelerators or catalysts are thoroughly mixed with the resin. Failure to do this can be a cause of the finished product not developing all its potential properties. Indeed, parts of the resin mix may not even set.

The fourth factor which may affect the setting of a resin is the environment in which the work has to be done. For instance, there may be chemicals present which inhibit the setting of a resin. Alternatively, where chemicals used as hardeners are hygroscopic and, therefore, destroyed in wet conditions, the resin mix must be kept dry until the cure is complete.

In most of the repair procedures which will be described, resins will not be used alone. Their properties will be modified by the addition of fillers chosen with the duty in mind. There is a whole range of powder fillers, some of which modify the rheological properties of the mixture appreciably. For many repair uses it will be desirable to produce this thixotropic property, that is to say, mixes which flow easily under a small force but which remain in position when the force is removed. Such mixes can readily be applied by trowel or knife. The property of thixotropy may be particularly important if the resin is to be applied to a hot surface. In this particular case, although the heat will reduce the overall viscosity of the mixture, the initial effect will be to reduce the viscosity of the resin portion and hence make the whole mixture more fluid.

Fibrous fillers are also used in resin mixes when the aim is to develop tensile strength in the system. The common materials are asbestos and glass fibre. Glass fibre is, of course, well known as the reinforcing medium used with resin for the production of laminated constructions. Glass fibre is available in a number of forms namely, chopped strand mat, cloth and rovings, the most common form used in repair applications being chopped strand mat.

Fillers have other effects on the properties of resins. One effect is that the contraction on setting is reduced; this being important when large holes have to be filled. A significant effect so far as the set resin is concerned is that thermal expansion is reduced. An unfilled resin may have a thermal expansion of 70×10^{-6} whereas the same resin filled will have a thermal expansion of 25×10^{-6}.

There are many resins available which will fit the description given at the beginning of this section. Some of the better known of these are polyester, epoxy, phenol formaldehyde, resorcinol formaldehyde and furane resins. Of these, only epoxy and polyester resins are used in quantity for repair work.

A wide variety of epoxy resins is available. These have the same basic formula but different molecular weights. The resins produced range from low viscosity syrups to solids and all of these can be used given the right circumstances. The resins can be modified by the addition of plasticisers, reactive diluents and other additives. The matter is further complicated by the fact that, in addition to the various resins produced, different types of hardeners and accelerators are available. The selection of the hardening system is of considerable importance since it may govern many factors, such as pot life, curing time, the effect of temperature on the rate of cure and the effect of the environment, e.g. whether or not the resin mix will set under water. The physical and chemical properties of the set resin also vary with the hardening system used.

To the layman this picture is confusing and the uninformed user may find it helpful to work initially with a single system. One will gain knowledge about the limitations of the system and can then probe other systems in the light of information acquired.

With polyester resins the matter is a little different and perhaps more simple. There are three main types, namely orthophthalic, often referred to as general purpose resins, isophthalic, and bisphenol. The most important difference in the three types so far as repair work is concerned is in the chemical resistance of the set resins. In this respect the bisphenol resins are superior. There are applications, for example in handling wet chlorine, where this superiority is very marked, but for the majority of repair applications a good quality general purpose resin may be used. The catalysts and accelerators can be varied but the variation is generally more of degree of activity than type and therefore, selection is determined by the hardening time required rather than any effect on the properties of the cured resin. It is possible to obtain resins with the accelerator added by the manufacturer which simplifies site work.

The selection of the most suitable resin system for a particular application is obviously of some importance, but a detailed knowledge is outside the scope of the normal maintenance engineer. There are a number of proprietary products marketed specifically for repairs and a lot can be achieved by the use of these products, but if full advantage is to be taken of the range of materials and techniques, expert knowledge should be obtained.

3.2 Techniques

The basic technique of using synthetic resins for the repair of equipment is quite simple in concept. Metal which has been corroded or worn away is replaced by the synthetic resin. The first essential is, of course, that resin must adhere well to the metal which is left. The efficiency of this bond depends greatly upon the degree of cleanliness of the surface and, to some extent, its roughness. In general, the surface must be clean, free from oil and dust and in most cases dry. Ideally, the surface should be degreased and shot blasted. How far proper preparation can be achieved depends upon the circumstances of the emergency and whilst it is easy to specify what is proper preparation, there are many cases where circumstances have dictated that little or no preparation can be done and yet repairs have been effected successfully. Nevertheless, a good maxim is that the surface preparation should be as good as conditions allow.

When the surface has been prepared, resin is applied either with a reinforcing material, as in a normal laminating process, or mixed with a filler which produces a putty-like material. It is important that the resin is made to 'wet' the surface of the metal so that the maximum bond is obtained. In order to help the wetting out process, consideration can be given to applying a thin coat of unfilled resin before using the main mass of filled resin.

In the case of complicated shapes it is often possible to mould the resin repair to the required profile by use of simple moulds. It is helpful if these moulds are made of polythene to which resins do not stick, thus allowing their easy removal. When using moulds made of other materials, a release surface can be provided by covering the moulds with a plastic film. For epoxy resins, polythene film can be used; in the case of polyester resins, cellophane film is to be preferred. Grease can be used as a release agent but there is always a risk of contamination of the surface to which adhesion is required. When the repair cannot be moulded, the part is over-built and then hand-dressed or machined. When it is known that a finishing operation is required it is an advantage to use a filler such as slate rather than silica. This is because silica takes the edge off tools. It is possible to work to quite close tolerances by ordinary engineering techniques. When a resin is mixed with a filler a certain amount of air is incorporated in the mix and not all of this air will escape. Therefore, when a very good surface finish is required, it often pays to rough machine and then apply a further thin coat of resin before final machining is done.

The basic method can be varied according to circumstances; it may be possible for new pieces of metal to be fitted using resin as an adhesive; it has been used in conjunction with metal stitching. Where high strength is required, for example on the shell of a vessel where pressure might blow a resin patch, a steel clamp can be fitted either side of the vessel wall and the resin acts as a jointing material, the clamp providing the physical restraint. Because the resin is applied in a soft condition the clamp plates do not have to be a good fit. It is not possible in this paper to cover all the different methods. However, many applications require only slight variation to a few basic techniques which are easily adapted by the user once he is familiar with materials and has learnt to use them in a few simple cases. Techniques are illustrated further in the case histories quoted later in the paper.

3.3 Equipment

Equipment is required for (1) preparation of surfaces (2) mixing of resins (3) application and curing of resins. The type of equipment necessary depends upon the scale on which work is likely to be done. Much can be achieved with very simple equipment. Quite large jobs can be tackled with the minimum of gear if time to do the work is not of paramount importance. Factors which determine what is required are (a) standard of surface preparation which is necessary (b) the size of the job (c) the speed with which the work needs to be completed (d) the circumstances under which the work has to be done.

3.3.1 Surface Preparation

The preferred method for surface preparation is grit blasting. Grit blasting equipment is available to deal with a variety of conditions. It ranges from large units designed to deal with large surface areas which are heavily contaminated to small units holding about 2 lbs. of grit which can be used for surface areas of the order of 2 to 3 sq. ins. Three units are illustrated in Figs. (1), (2) and (3). None of these units are expensive, the larger two costing about £100 each. The largest unit is designed for open blasting and full protective clothing is required. The biggest difficulty with this equipment is the air supply. The requirement is for 125 cu.ft. per minute at 100 psi. The medium sized unit, which has its own recovery system needs 45 cu.ft. per minute at 100 psi. The small unit will work at 50-80 psi and the consumption is very low. However, blasting equipment is not always available, and even if available, cannot always be used. Therefore, other methods of preparation have to be considered. Power grinding equipment is useful for preparing local areas, but the tool which should always be available is the wire-brush.

Fig. 1 Grit Blasting Equipment

Fig. 2 Grit Blasting Equipment

Fig. 3 Grit Blasting Equipment

In addition to the mechanical preparation of surfaces it is generally wise to degrease. Degreasing is best done with a vapour degreasing unit but this is rarely available for plant repairs, and therefore, the first essential is to have a supply of a degreasing agent and brushes for swabbing a surface.

3.3.2 Mixing of Resins

If it is envisaged that resin will only be used in small quantities then the various ingredients can be obtained in small packs already apportioned. This is a convenient way of dealing with occasional small demand but can be wasteful and is not satisfactory if large quantities are to be used. Another disadvantage of simply mixing prepacked ingredients is that there is not the scope for adjusting proportions to meet different applications and conditions. When conditions demand flexibility in mixing, it is necessary to have apparatus for weighing. Because some of the components are used in quite small proportions a reasonably sensitive balance is required. Simple balances which will weigh to 1 gm are readily available. It is seldom that more than 5 kilos of resin are mixed at a time. Such quantities can be weighed out on household scales. Suitable weighing equipment is shown in Fig. 4.

Good mixing of the various components in a given formulation is absolutely essential. Small mixes can be done by hand and it is convenient to mix in disposable paper cups. The most useful tools for mixing are spatulas. Addition of fillers increases the difficulty of mixing but if the quantity of resin required is small, mixing can still be done by hand. Even if large quantities are required it is still possible to mix by hand, but work is then slow and tedious and there is a tendency to use less filler than is really required. The best solution when large mixes are involved is to use a mechanical mixer. The action of the mixer is quite important; to mix filled resin well, the mixer should have a good shearing action. A suitable machine is a dough mixer which is illustrated in Fig. 5.

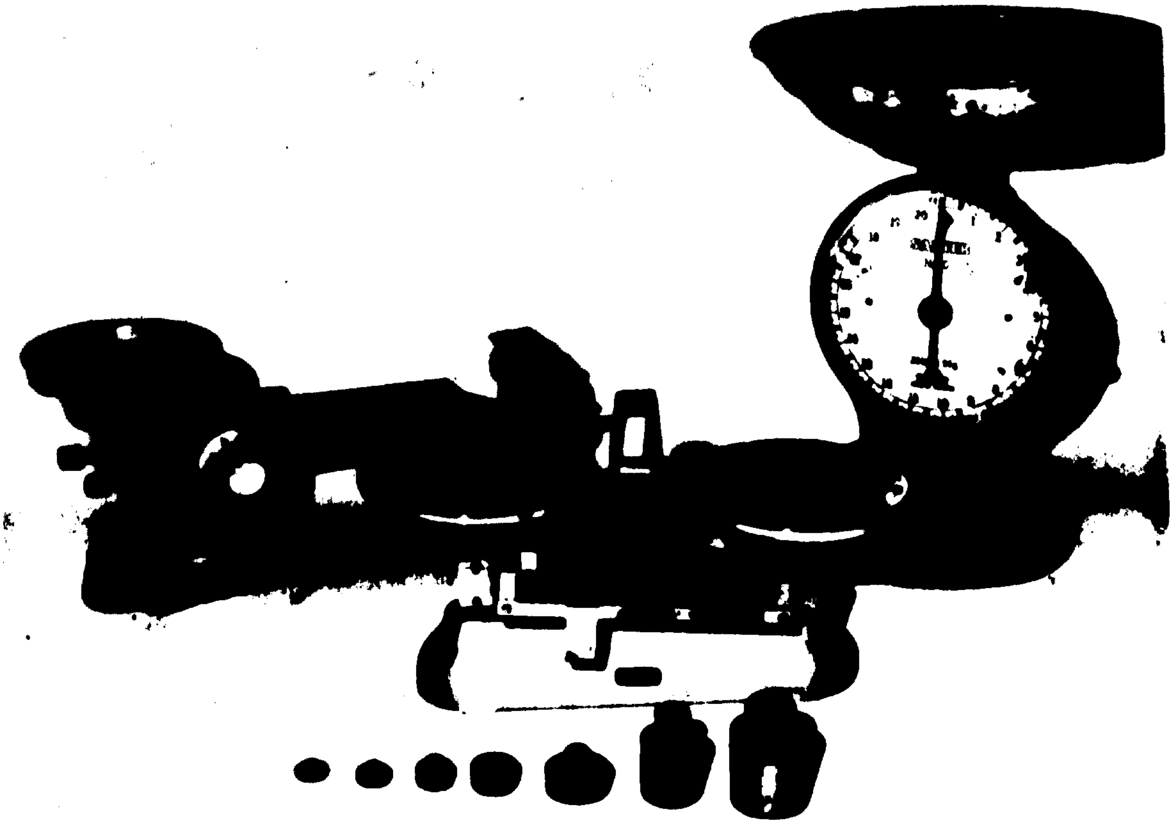

Fig. 4 Equipment for Weighing

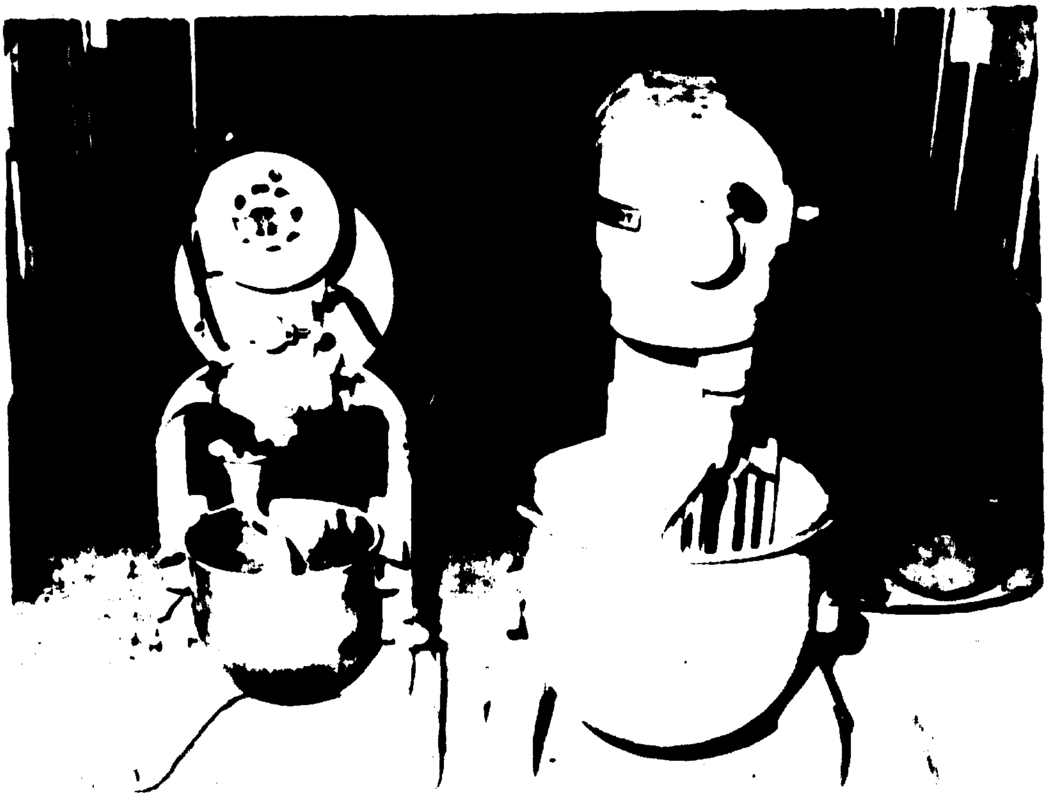

Fig. 5 Mixing Equipment

3.3.3 Application of Resins

If the resin is being applied with glass cloth as a laminate, brushes and rollers are required. The brushes should be fairly stout, the rollers serrated (see Fig. 6). For the application of filled resin the usual tool is often the spatula used for mixing. When large areas are to be covered, bricklayers' or plasterers' trowels are used.

Once applied, the resins have to cure, and for most applications the curing will take place at ambient temperature. However, when considering emergency repairs, downtime is vital and it may be necessary to accelerate the curing process. If the equipment being repaired is small the most convenient and controlled method of applying heat is to place the repaired item/equipment in an oven. It is obvious that there are many cases when this refinement will not be possible. Nevertheless when it is still important to reduce the curing time, improvisation can achieve a lot. A steel plate set up with a blow torch behind it will provide a good source of radiant heat. Copper pipe or even a rubber hose wrapped round a repair and connected to a steam supply can be used to reduce curing time.

Below about 5°C the cure of most resins is severely retarded and may be completely inhibited. Such situations can be dealt with by fairly simple heating equipment. Air heated by a propane burner can be ducted into an enclosed space. If the work is in the open it will be necessary to erect a temporary cover. An easy method of doing this is to build a light wooden frame and cover it with polythene film.

3.4 Limitations of the Use of Resin Repairs

The first essential property of a repair is that it should withstand, at least for a time, the chemical and temperature conditions for which the particular piece of equipment is used. What this time has to be before the repair is worthwhile is entirely a matter of the circumstances which apply on

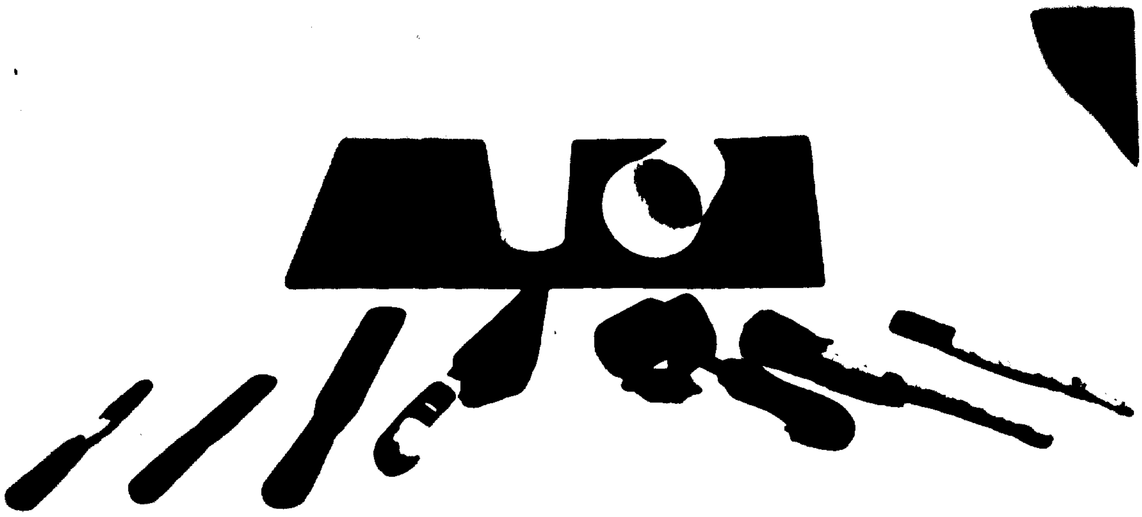

Fig. 6 Equipment for the Application of Resins

the particular job. So far as chemical resistance is concerned, some indication can be obtained from chemical resistance tables but quite often the best resin to be used has to be found by experience and testing. For example, it is known that polyester resins have better resistance to strong oxidising conditions whereas epoxy resins are better in hot alkaline conditions. Where an organic solvent or mixture of solvents is concerned the problem is a little more complicated and it may be that none of the resins so far mentioned have suitable resistance for particular solvents. Sometimes such a difficulty may be overcome by the use of a duplex system. Phenol formaldehyde, resorcinol formaldehyde or furane resins may have the required chemical resistance, but have other disadvantages, such as poor adhesion or high shrinkage on setting. In such cases epoxy resins may be applied to the metal surface to obtain the adhesion and build up; the second resin is then applied as a type of surface coating to protect the epoxy resin.

When it is known that none of the resins available are suitable for a process condition and the only alternative procedure involves a plant shut down, the situation need not be hopeless. This is illustrated by the following case. A small branch at the base of a distillation column on a phenol plant was leaking. It is well known that hot phenol very quickly destroys most cold curing resins. A welded repair could only be achieved by shutting the plant down, cleaning out the column and making the area generally suitable for a fire permit to be issued. This would have meant fairly long downtime. A remarkably satisfactory repair has been effected for the use of filled epoxy resin. The method used was to cast a large block of resin of the order of 1 cu.ft. round the branch. The resin is placed every four to six months and so far the column has been kept in operation for about three years.

Temperature limitations depend upon end use. Resins lose strength as the temperature rises and generally cannot be considered for use in this type of application above 150°C. The other factor which has to be taken into account is the thermal expansion of resins which is much higher than that of metals. The forces produced by the differential thermal expansion work against the adhesion. The thicker the patch, the higher the forces involved. Unless a resin patch is restrained, thermal expansion may limit the life of a patch at temperatures above 70°C. The solution at higher temperatures is to use a steel fitting to combat the forces of expansion.

The third factor to be considered in judging the limit of use is, of course, mechanical strength. Adhesion in shear can be as high as 2000 psi but in peel it may be as low as 15 psi. It follows, therefore, that wherever possible the repair should be made so that the bond is in shear. Glass reinforcement will increase the tensile forces which can be applied, but it must be remembered that such a system is likely to be strain limited. The modulus of glass reinforced resins is only 1×10^6 lbs./sq.in. The practical implication of this so far as emergency repairs are concerned can be illustrated by considering a pressure vessel. If corrosion of the metal had taken place and it was considered necessary to reinforce it would not generally be practicable to apply a laminate on the outside of the vessel for this purpose. Bearing in mind the low modulus, an excessive thickness would be required before the two systems would be strain compatible.

3.5 Costs

In the majority of cases the cost of the repairs using the techniques described is low. High capital cost equipment is not required for the work and only seldom is expensive machining involved. In bulk, polyester resin costs 1/6 to 3/- per lb. and epoxy resins cost approximately 7/- per lb. Fillers such as silica flour or slate powder cost 1d. or 2d. per lb. and glass fibre is 3/- to 6/- per lb. according to the form in which it is required. Proprietary kits are available, though the cost is, of course, much higher than for resin bought in bulk. However, the quantities of resin used in most repairs is very small.

4. APPLICATIONS AND CASE HISTORIES

4.1 Pumps

Pumps are produced in a wide variety of metals and causes of failure are so diverse that it is difficult to generalise. When considering repairs there are a number of difficulties to be taken into account. Not all materials can be welded. Where welding is possible, the process may cause distortion and this can be disastrous. Following welding it is often necessary to machine to restore profiles and maintain clearances. Such machining can be very time-consuming. Methods of overcoming some of these difficulties are discussed in the case histories which are quoted below.

4.1.1 Example

In 1958 the heavy iron casting forming the casing of a river water pump was found to be severely eroded, especially where the 30 in. diameter stainless steel sealing rings seated in the top and bottom halves of the casing. The eroded parts were shot blasted and filled up with epoxy resin filled with aluminium powder. Different techniques were used to obtain the required profile for the two halves of the body. The reason for adopting the different techniques is that whilst the top half could be removed by crane and transported to machine shops the bottom half was bedded in concrete and had not been moved for thirty years and it was deemed unwise to attempt a move because of the danger of breaking the casting. In the case of the top half the damaged area was simply over-filled with resin the the required profile achieved by machining. The damaged areas on the bottom half were slightly over-filled and whilst the resin was still soft the sealing ring which had been lightly greased was pushed down into the resin to mould it approximately to shape. After the resin had cured the sealing ring was withdrawn and an accurate profile produced by hand scraping. The extent of the repair can be judged by the fact that about 25 lbs. of resin (1/4 cu.ft.) was used. In addition to the sealing ring seats, other parts of the casting where erosion had taken place were built up. After running satisfactorily for a year the pump was opened up and examined. The seats for the sealing rings were in perfect condition. In the body of the casing whe some resin cement patches had been applied to deep holes, the cement had withstood the erosion although adjacent cast iron areas had become deeply pitted. These pits were repaired with resin cement patches and twelve years after the original repair the pump is still operating satisfactorily. A general view of t pump is shown in Fig.7, a repaired seat is illustrated in Fig.8. Fig.9 shows th new hole which had developed in the cast iron after a year of operation. This w has been repeated with similar pumps. A point to be remembered in dealing with this type of repair is to make sure that the resin repair is made on to sound material. Cast iron on this duty may be heavily graphitised and what is at firs sight sound material may, in fact, be very weak. Such material should be remove before applying the resin.

4.1.2 Example

Aluminium castings which are difficult to repair by welding can be repaired quite easily with resins. The pump illustrated in Fig.10 had suffered fairly severe corrosion due to partially carbonated ammonia liquor. The repair was made by simply degreasing the damaged area prior to resin being trowelled on to the surface. The surface was so rough that shot blasting was pointless. The finish shown in Fig.11 was achieved without machining. Whilst the resin was soft, a sheet of polythene was pressed onto the resin and peeled off after the resin had cured. As a demonstration, another pump was treated but only half the damaged area made good. This is illustrated in Fig.12.

4.1.3 Example

A petrohydro treatment plant was served by two feed pumps delivering the feedstock. The pumps were eight stage centrifugal pumps delivering 31 m^3 per hour at 570 lbs./in^2. These pumps needed considerable maintenance during the first year in service and the life of the pumps was doubtful because of quite severe erosion/corrosion of the cutwaters. The pumps were made of cast ste difficult to repair by welding because of possible distortion and the estimated

Fig. 7 River Water Pump - General View

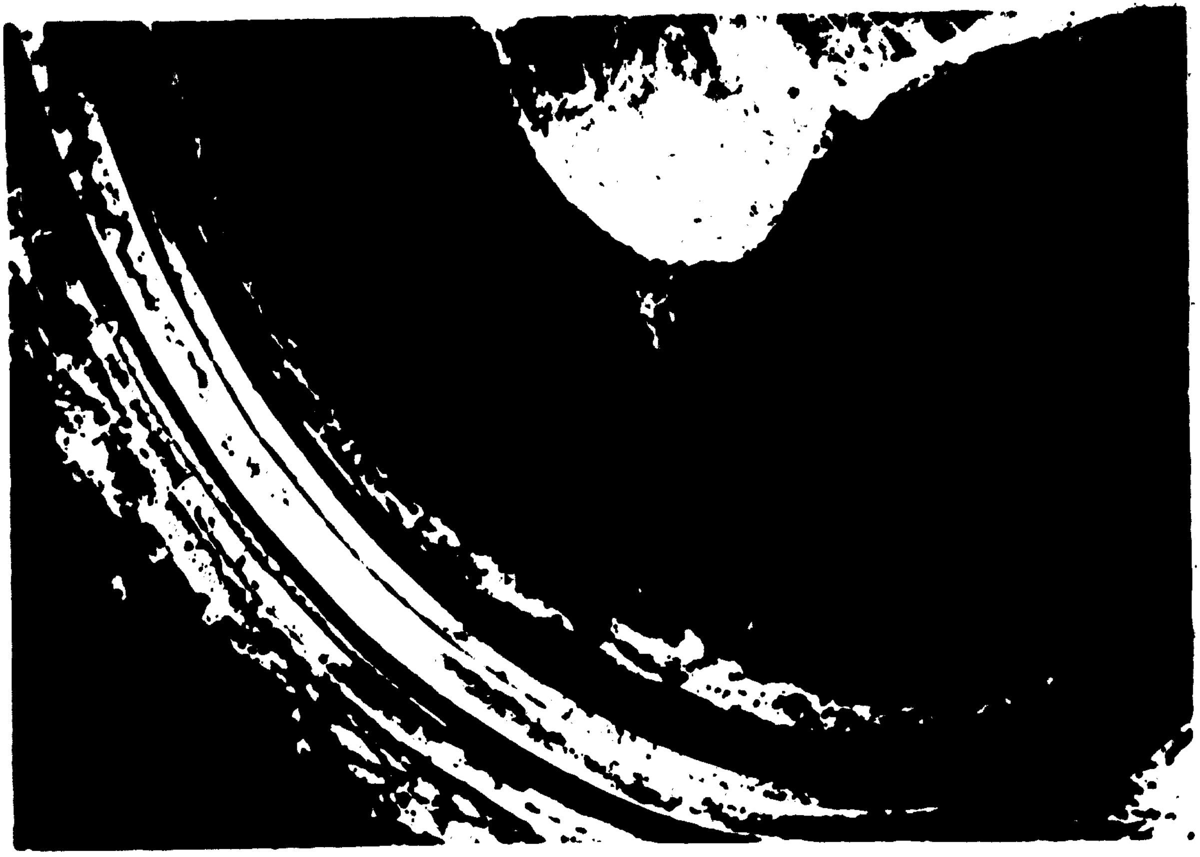

Fig. 8 River Water Pump - Repaired
Seat for Sealing Ring

Fig. 9 River Water Pump - Erosion of Cast Iron

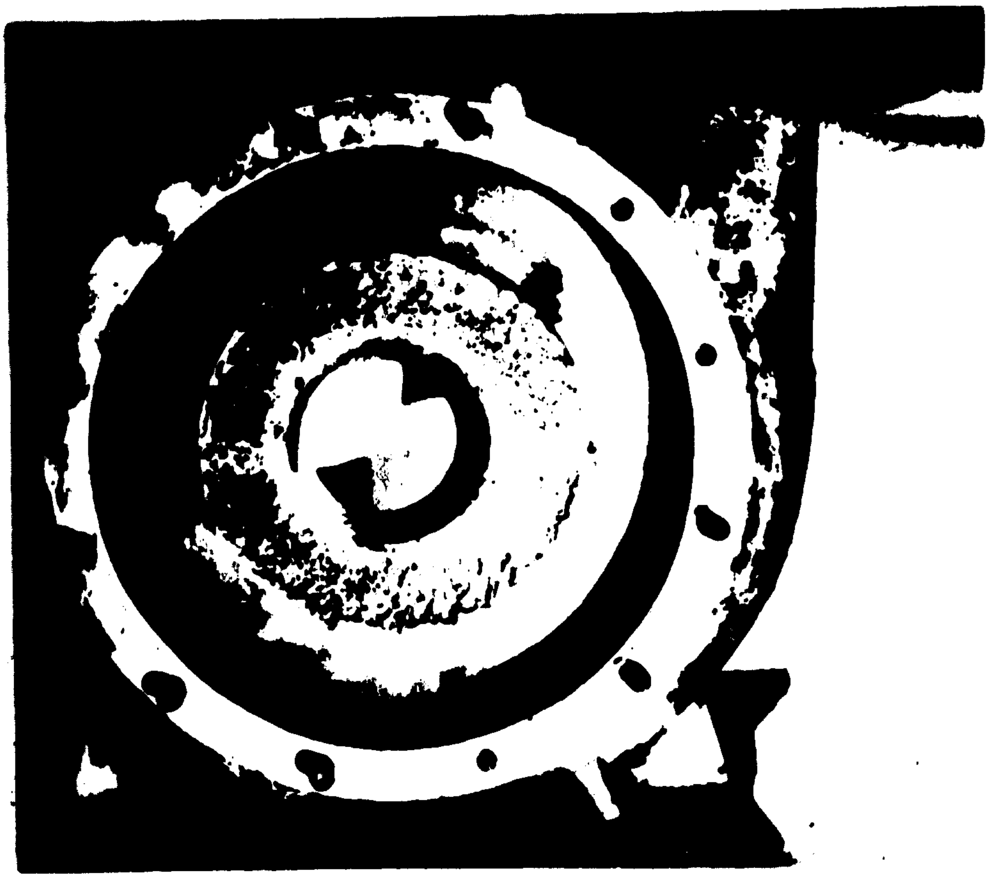

Fig. 10 Aluminium Pump Body - Before Repair

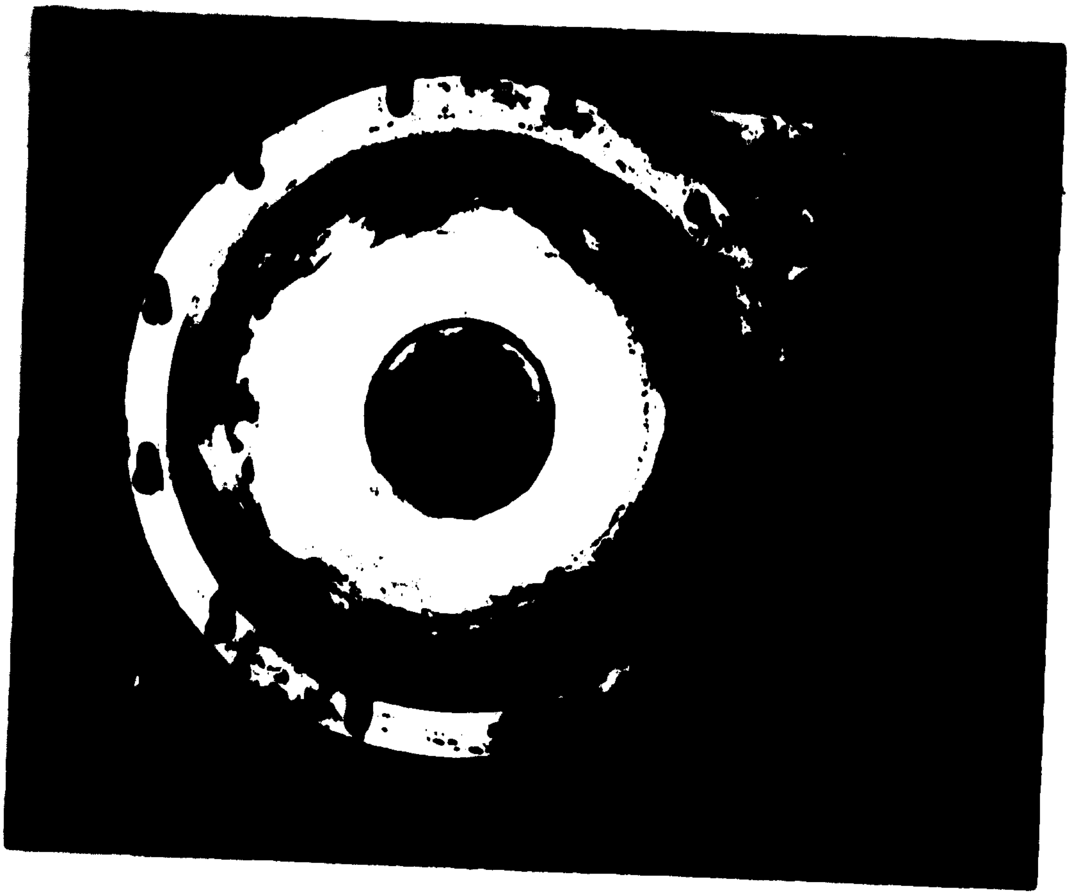

Fig. 11 Aluminium Pump Body - After Repair

Fig. 12 Aluminium Pump Body - Part Mapped

time for welding and subsequent machining was two weeks. The plant concerned supported a very large petrochemical complex, and as the pumps were critical items of equipment, this delay was unacceptable. Not only would replacement pumps have cost over £2,200 but, more important, delivery was about six months. Because of the emergency situation it was decided to build up the cutwaters with epoxy resin filled with slate powder. The resin build up to the cutwaters was moulded to the correct profile using simple moulds made from polythene block. After the resin had cured and the moulds removed the very minimum of hand dressing was required before the pump was ready to be reassembled.

Excluding dismantling times the repairs were completed in two days and have given satisfactory service since 1963. At the time of the work done, the repair was regarded as emergency work and a new pump ordered immediately. Service experience was so satisfactory that the new spare pump was transferred to another plant.

Fig.13 shows a general view of one half of the pump casing. Fig.14 and 15 illustrate the damaged cutwaters, Fig.16 shows the repaired cutwater.

4.1.4 Example

In the section on limitations of the technique attention was drawn to the differential thermal expansion of resin and cast iron or steel. It was stated that an unrestrained patch of resin, when required to work at temperatures above 70°C, would probably fail because the forces induced work against the adhesive bond and, because it is a buckling force, the bond is put into peel which is the least favourable case. Nevertheless, even when operating temperatures are considerably higher than 70°C, there is advantage to be gained in the short term by use of the technique. This is illustrated in the following case. A large petrochemical plant was served by two six stage centrifugal pumps each of which was required to pump 100 tons per hour of boiler feed water . The operating temperature was about 110°C and the delivery pressure 300 psi. The pump bodies

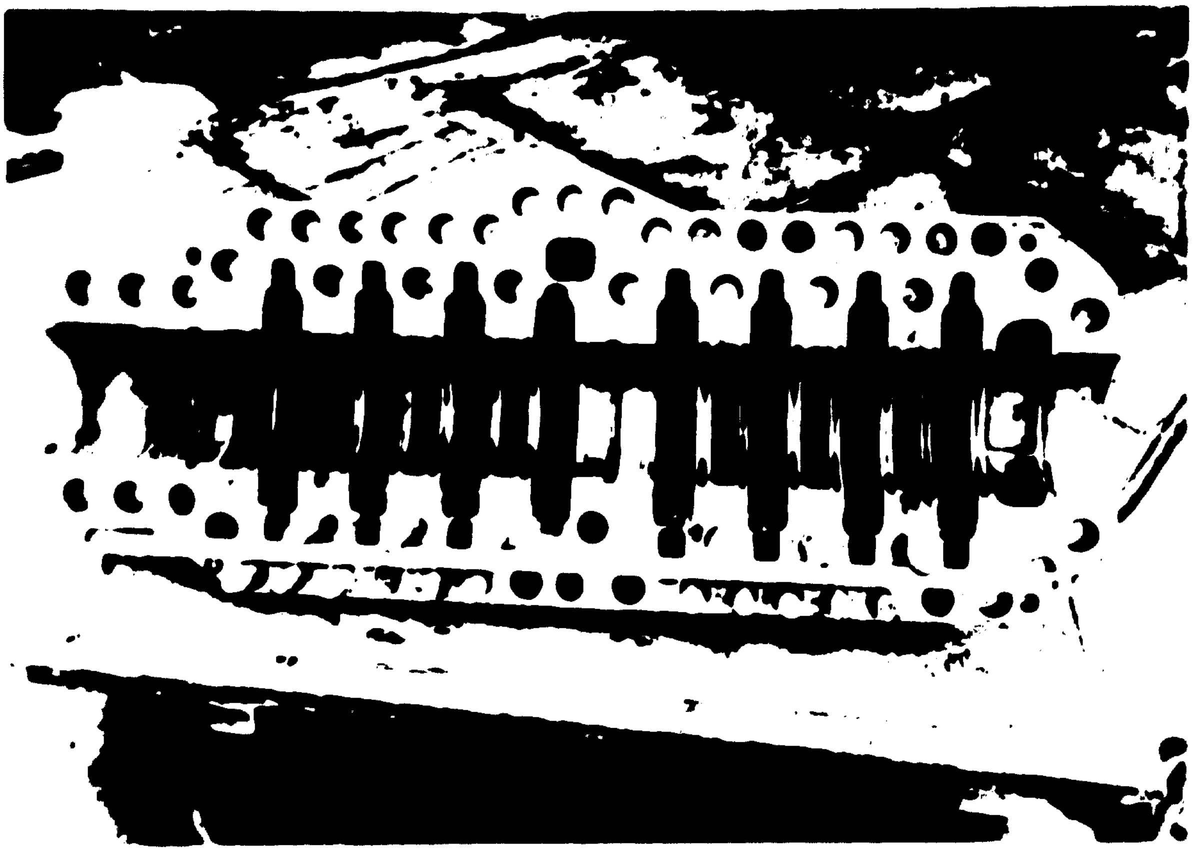

Fig.13 Pump Casing - General View

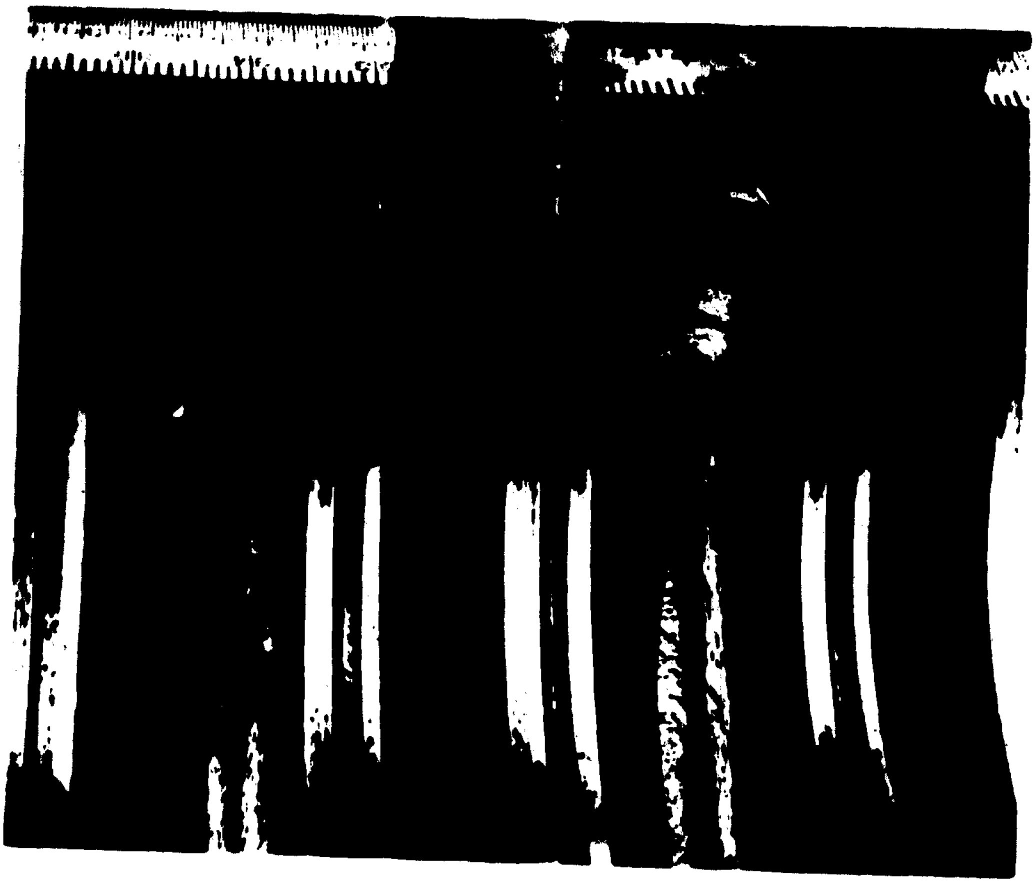

Fig. 14 Pump Casing - Damaged Outwater

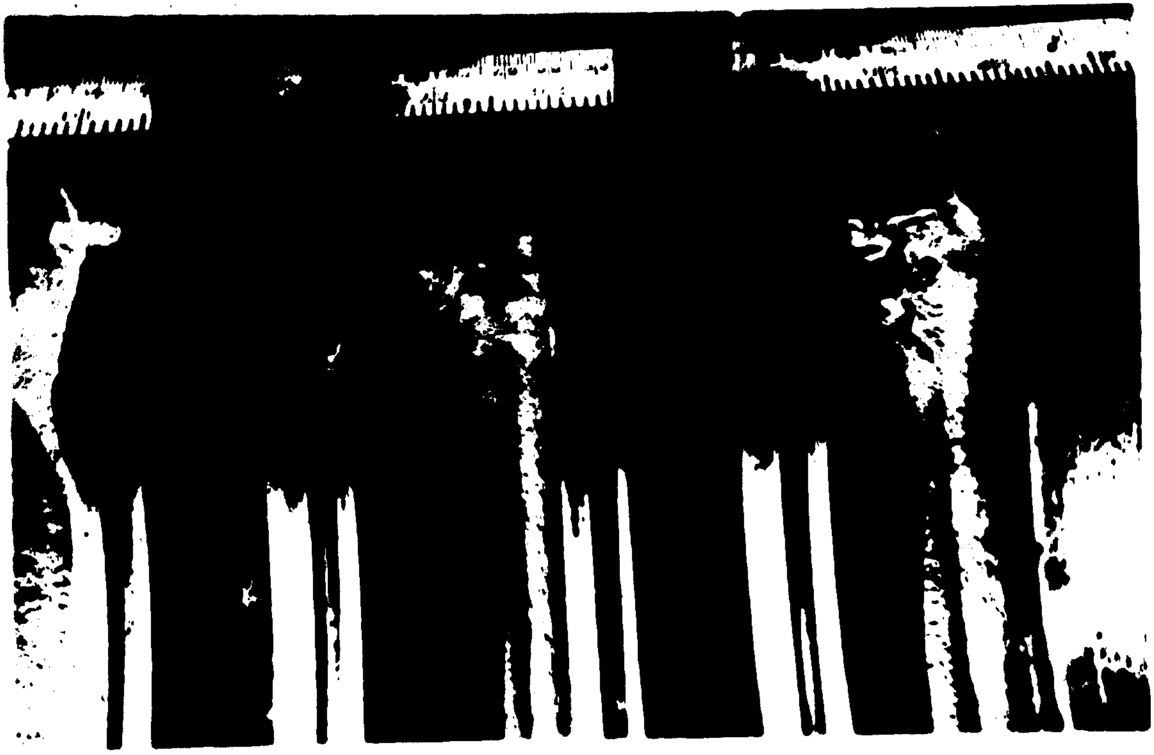

Fig. 15 Pump Casing - Damaged Cutwater

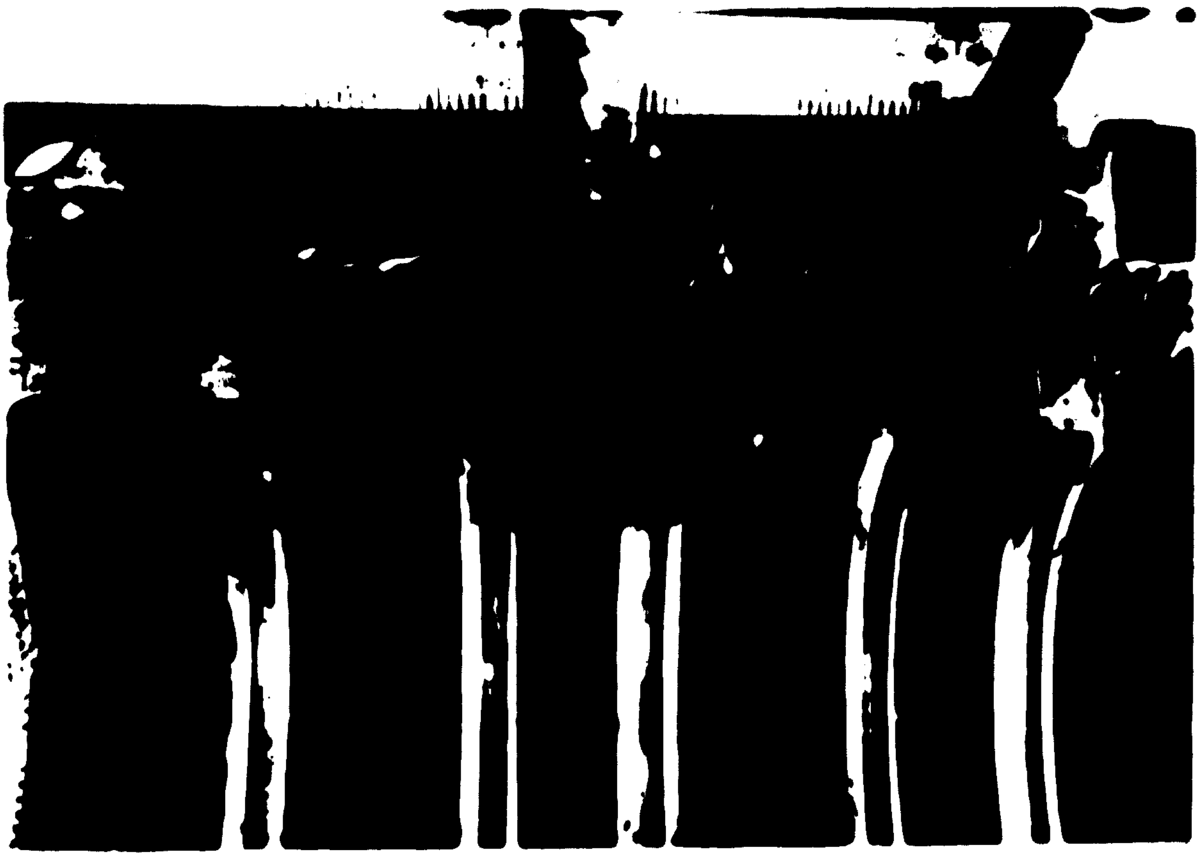

Fig. 16 Pump Casing - Repaired Cutwater

rotors and stators were originally supplied in cast steel but after trouble in service the rotors and stators were replaced in 13% Cr steel. The casing then suffered erosion which led to by-passing between stages and the efficiency of the pumps dropped, in one case down to 30%. Delivery of new casings made in 13% Cr was 3 to 4 months and the estimated cost through loss of production because of poor performance of the existing pumps was very high. In spite of the high operating temperature the casings were built up with an aluminium filled epoxy resin. The repair in one pump lasted the required 4 months until new casings were obtained in a different material. The repair in the second pump had to be repeated after an operating period of about 3 months. The total amount of resin used in these repairs was only worth about £1 but the saving to the plant was probably of the order of £10,000.

4.1.3

The examples quoted demonstrate the use of technique for the repair of pumps over a fairly wide range of circumstances and the success in each case has been fairly substantial. There are dozens of other examples which could be quoted which include the simple filling-in of holes in pump cases, building up of the tips of impeller blades, repairing holes in impeller blades and even in open type impellers building up complete blades. Such repairs have had a life ranging from a few days to a few months but almost invariably have enabled a plant to operate until spare equipment has been obtained and installed.

4.2 Tanks

The trouble which is generally experienced with storage tanks is leaks due to corrosion. This may be (a) simple corrosion of the steel by the contents, (b) a corrosion/erosion effect in cases where solids are present, (c) corrosion of the outside of the tanks in aggressive atmospheres which often takes the form of deep pitting and leads to holes, (d) corrosion from the underside of storage tanks which have been in service for some years, causing leaks to develop. In addition to corrosion there can be mechanical damage or in the case of tanks of rivetted construction the seams may develop leaks.

If a hole in a tank can be repaired by simply welding a patch over a hole then that is the most simple and, if facilities are available, the quickest, and probably the best, solution. However, there are many situations where the remedy is not quite so straightforward. The most obvious difficulty, so far as welding is concerned, is that of doing the work in fire risk areas. It is often possible that fairly simple precautions may suffice but, on the other hand, it may be necessary to restrict other operations, and extensive purging may be required before clearance for the work can be given. A difficulty which arises when a large tank is leaking because of corrosion from the underside is that of locating the leaks. In such cases it is generally not possible to gain access underneath the tank for survey purposes and the solution frequently used is to weld a new base in the tank. A further complication when a new base is required in a tank for whatever reason is the size of plate which can be introduced into the tank through the manhole. This increases the time taken for the job and the cost.

With tank repairs the areas involved may be quite large. The usual method of tackling these repairs is to apply to the steel a simple laminate of resin and glass fibre, generally in the form of chopped strand mat. The resins generally used for the work are the polyesters. The reasons being that (a) they are much cheaper and (b) much easier to use for laminating. Such laminates can be applied with the very minimum of equipment and in fact the method is often referred to as bucket and brush. The resin is simply applied by brush to successive layers of mat which are laid up over the damaged area. Care should be taken to work the resin into the glass so that it is fully wetted and the air eliminated. Except where the repair is very small indeed, a roller should be used after each layer of glass and resin is applied to make sure that a laminate of good quality is obtained. Although very large areas can be covered with laminate applied by hand, the time taken might be longer than is convenient to plant. Application times can be reduced by using special spray equipment which is available for the purpose. The components of the resin are supplied to a twin spray head by metering pumps and mix at the spray head. The equipm also chops glass rovings and deposits the glass on the surface with the resin. The glass and resin deposited has then to be compacted by hand rolling to achieve a laminate of reasonably quality. When a resin glass laminate is applied to the inside of a tank, and it is known that the contents of the tan have proved very corrosive to the steel, it is wise to check the laminate to make sure that there are no holes, however small, left in the laminate. This can be done quite simply with a spark tester. Holes are located by a concentration of the discharge. The equipment can be purchased for about £20

If the surface of the tank is badly pitted the application of a simple laminate is not very easy because of the difficulty in making contact between the glass and the surface of the steel. The solution to this problem is to apply a render of a mortar made with either epoxy or polyester resin. Such a mortar can either be applied of such a thickness that the mortar itself protects the tank from further damage or it may be designed merely to fill the pits before the application of a laminate. The practice of applying a mortar is also useful in the case of tank bottoms where corrosion has taken place from the underside. In this case the severe corrosion is often very localised and a sealing layer is required over the base rather than any contribution of strength which could be attained from a laminate.

4.2.1 Example

In 1960 some large mild steel storage tanks which had been in use many years were developing leaks in their bases, caused by corrosion from t underside. The tanks were 1500 m^3 capacity and were situated in a fire risk area. The positive way of repairing the tanks would have been to sole in n bases but because of the site conditions this would have been difficult and expensive. It was decided to render the base with a resin cement. Initially a polyester cement was selected but on the first occasion the resin was app it failed to cure properly. This was because, although the steel had been grit blasted, there was apparently a trace of phenolic material left in the steel which inhibited the setting of polyester resins. An epoxy resin mortar was then tried which cured satisfactorily. The whole base was covered with a layer of cement varying in thickness from about 1/16" to 3/16". This stopped the leaks effectively and the cost of the operation at that time was about £400. By comparison, the estimated cost of fitting a new steel bottom was £4,000. Other tanks have since been treated in a similar manner and most of these are still in service. It should be mentioned that work of this nature requires very little skill.

4.2.2 Example

The roof plates of storage tanks in a large storage installation had suffered severe local corrosion which had resulted in a number of holes and cracks. For reasons of safety there was a nitrogen blanket over the contents of the tanks and the holes and cracks were the cause of a serious loss of nitrogen. Permanent repairs by welding could only be contemplated after the tanks had been emptied and steamed out. Stop-gap repairs had previously been made by fitting mild steel plates to the tanks with self-tapping screws. This was a slow process and not very successful, especially when the leaks were in positions where plates were lapped or where the roof joined the side of the tanks. Successful repairs were effected by covering the holes and their immediate surroundings with a laminate of polyester resin and glass mat.

4.3 Gasholders

A common form of trouble with gasholders is holes in steel due to atmospheric corrosion. Patching by welding may be quite impossible whereas it may be possible to make resin repairs without even taking the gasholder out of service.

4.3.1 Example

A large gasholder used for acetylene had become holed due to atmospheric corrosion. Because of the contents of the vessel, extreme care was necessary and either leaks had to be stopped immediately or the vessel taken out of service. The holes were quite small and the gas leaks were controlled temporarily by fitting wooden plugs. Because of the danger of igniting the acetylene by a spark, it was not possible to clean the surface of the steel to what would normally be regarded as the acceptable standard. Nevertheless, glass/resin laminates were applied over the wooden plugs and the adhesion obtained was quite sufficient to seal the leaks and keep the gasholder in service for some years until the plant was shut down.

4.3.2 Example

The crown of a gasholder, capacity 2,500 M^3, was severely corroded. The estimated cost of renewing the crown was £4,000. The cost of repairing the crown with a polyester resin and glass mat was £400 including the cost of shot blasting. The repair was adequate to keep the gasholder serviceable for about four years until the plant was closed down.

4.4 Process Vessels

It is very difficult to generalise about the use of resins for repairs to process vessels, as these are so numerous in their shape, size and design, and as the conditions under which they operate are equally diverse. Nevertheless, where there has been a loss of metal for one reason or another, the basic technique can be used. It may be that a surface of a flange has been corroded and as a result the making of a tight joint is difficult or impossible. In such a case the lost metal is simply replaced with a resin cement. It is possible for a vessel to become holed due to a localised erosion/corrosion effect, e.g. near to an inlet, in which case the wear will not be even. Should this occur in a vessel where there is more than a few pounds positive pressure or where there is a vacuum it is best to make use of the "pot mender" type of repair - this is illustrated diagrammatically in Fig. 17.

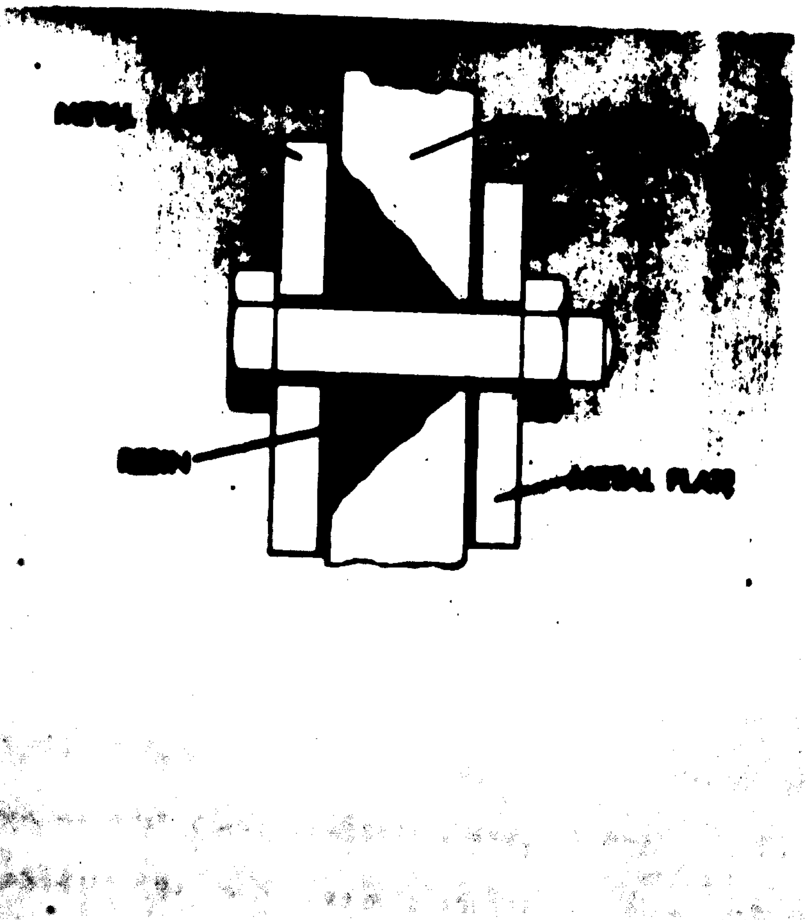

FIG. 17 - Diagram of 'Pot-[illegible]' Repair

Under the section on limitations of resin repairs, attention was drawn to the relatively low modulus of resin/glass laminates and for this reason that they were hardly suitable for application to the outside of a pressure vessel to strengthen that vessel. However, use can be made of resins to keep pressure vessels in service by applying the resin to the inside to prevent further damage.

It is not uncommon for vessels to be stress relieved before being put into service and, as a rule, if any further welding is done, further stress relieving is necessary before the vessel is recommissioned. Should a crack develop in such a vessel it is sometimes possible to use resin to affect a repair. A method whichhas been used several times is to fit a steel band round the vessel. This may be fitted in two or more bolted sections. The clamps do not have to fit exactly the contour of the vessel, and normally there will be a varying gap. This gap is filled with resin. In practice, excess resin is applied to the surface of the vessel and then the clamp fitted. As the clam is bolted up, the excess resin is squeezed out.

4.4.1 Example

In 1960 an inspection of some CO_2 towers on an ammonia plant showed th bottom 10 ft. of the vessels below the packing had suffered severe local corrosi in the form of deep pitting. The vessels operated at 55 ats. and at slightly above ambient temperature. The vessels were still serviceable but corrosion ha to be stopped otherwise the wall thickness would be reduced below the safe limi The surface was lightly grit blasted and a filled resin mix trowelled over the surface. The resin was applied in a series of thin layers. This was done to reduce the possibility of getting air pockets in the resin which is easily done if a single thick layer is applied especially over a pitted surface. There is danger of a pressure failure if air holes are left in such a coating on the walls of a pressure vessel handling gases. Organic materials may be slightly permeable to gases at pressure and if there is a pocket in a coating a gas pressure can slowly build up in that pocket. This does not matter so long as the vessel is on line, but if the pressure in the vessel is suddently reduced the resin layer covering the pocket can be burst by the internal pressure which has been built up. The vessels which were treated in the manner described are still in service and are illustrated in Fig. 18.

4.4.2 Example

A number of years ago a vessel was required urgently to hold brine from an underground gas storage installation whilst degassing took place. The only vessel available was pitted. The vessel was made serviceable in a few days by blasting and applying a rendering of an epoxy resin mortar. The work was done in an area remote from any services and the only equipment necessary for the work was a portable compressor and shot blasting equipment. The tank is illustrated in Figs. 19 and 20.

4.4.3 Example

During the last two years a number of stainless steel vessels on a plant producing polypropylene have suffered stress corrosion cracking. The vessels operate at about 25 psig and 100°C. To repair by welding would have involved shutting the plant down and because of the fire risk cleaning and purging of the equipment would also have been necessary. The effort and cost would have been considerable and the loss of production very serious. As it was considered that the vessels, although leaking, could safely contain the pressure, repairs were made by laminating over the whole of the outside of the vessels. Both polyester and epoxy resins were used for the work. Polyester resin was used for the vessels which could be taken off line for a short time, and epoxy resin used for vessels which had to be treated hot.

4.5 Heat Exchangers

Resins can be used in three ways to prolong the life of damaged tube bundles:-

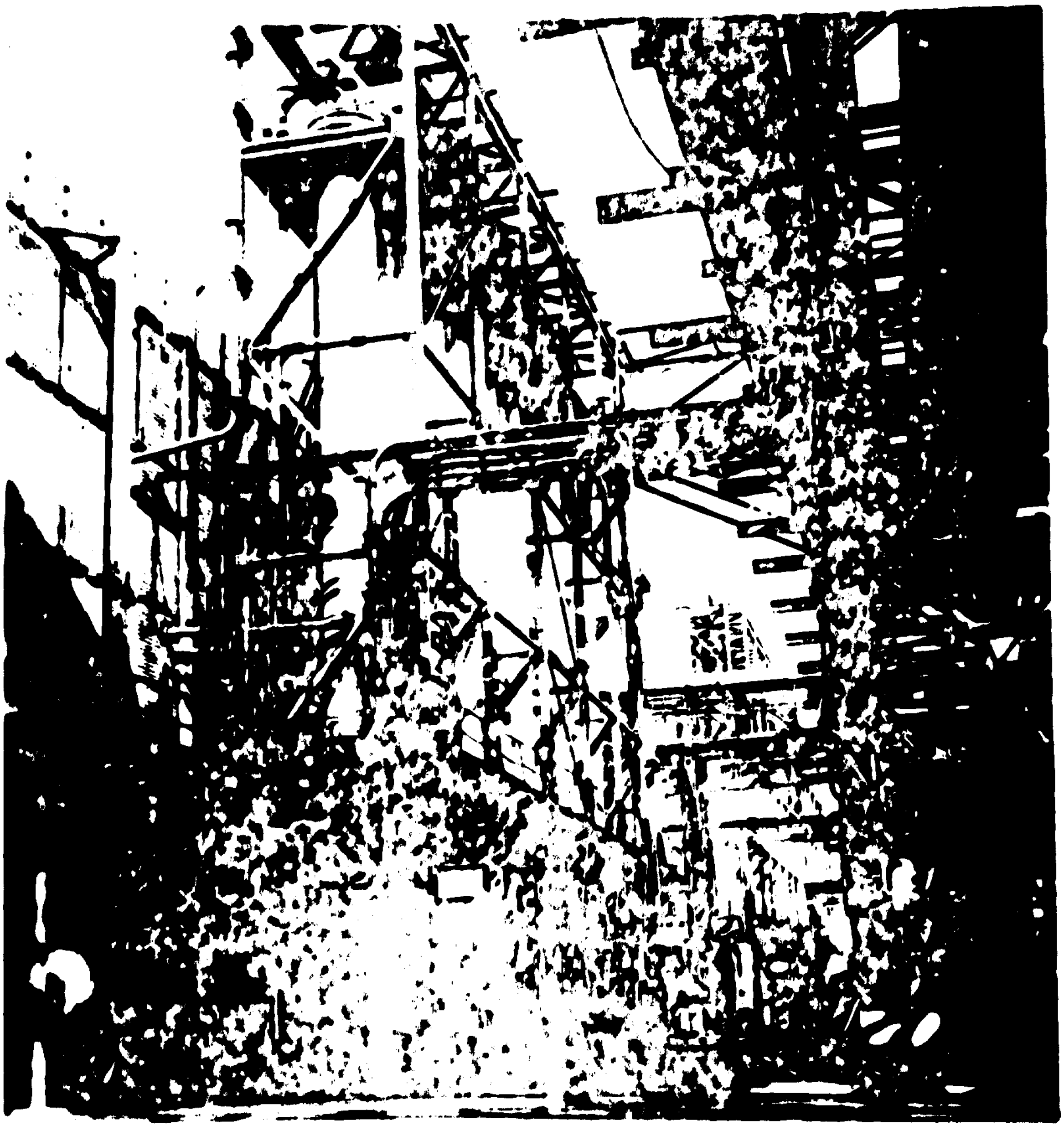

Fig. 18 CO_2 Towers

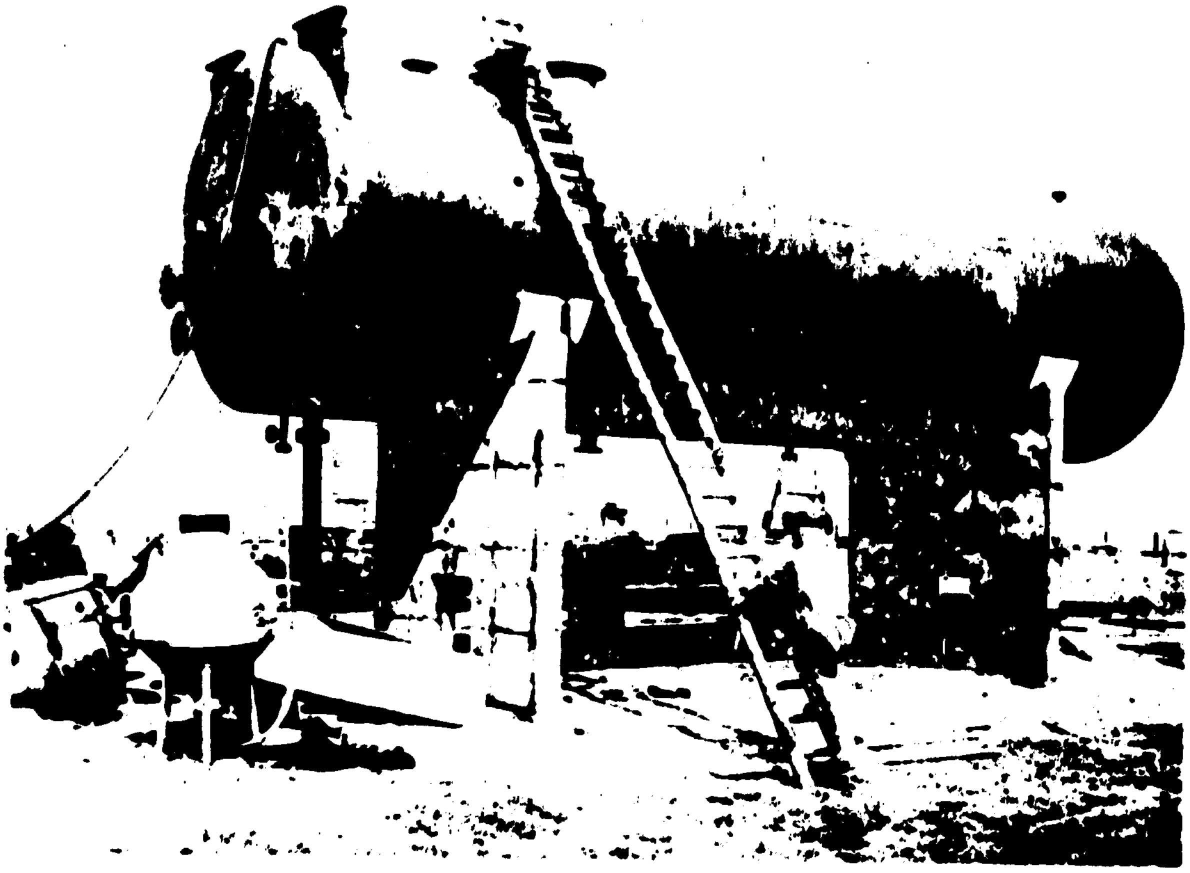

Fig. 19 Brine Degreasing Tank - General View

Fig. 20 Brine [illegible] [illegible] [illegible] - Showing [illegible]

(a) When only a few tubes are holed, tube bundles can still be operated provided the damaged tubes can be plugged. Welding of plugs is, of course, a standard method and in many cases perfectly acceptable. However, if there is a need to eliminate welding, either because conditions do not permit or because the facility is not available, plugs may be cemented in, provided always that the cement is suitable for the process conditions. The plugs do not have to be a good fit and therefore, need not be especially made. One method of improvisation is to use standard bolts of appropriate size. Cementing-in of plugs is particularly desirable when the tube bundles have been coated, since welding would damage the coating on the tube plate.

(b) It sometimes happens that corrosion of tubes takes place at one end only. If the corrosion is taking place internally it is possible to rescue quite large tube bundles very quickly and effectively by cementing ferrules into the tubes.

(c) A variation of example (b) is when the tubes have corroded on the outside and the corrosion is near to a tubeplate. These bundles can be rescued by casting a block of resin 5-6" thick immediately behind the tube plate.

This case is illustrated in Figs. 21, 22, 23.

All these techniques have been used successfully on a number of occasions.

Another source of trouble in heat exchangers is the end covers for water boxes. These are normally made of cast iron and corrosion is quite common. The first result is that the dividing plate ceases to be effective. Resins repairs are simple to do and if the end plate is coated at the same time further trouble can be eliminated.

This example is illustrated in Figs. 24 and 25.

4.6 Machines

Emergency repair work on machines ranges from simple repair of cracked castings, e.g. oil reservoirs on machines, to the repair of labyrinth seals on large compressors. Where working parts are concerned there are special considerations to be made. It must be remembered that filled resins are poor conductors of heat (a typical value is 4-5×10^{-4} cal./cm./°C) and therefore, the question of heat dissipation must be carefully considered before deciding to use resins for the repair of rubbing parts. Heat will not be dissipated as it would be with a metal and local high temperatures can easily be caused and a failure condition produced. Therefore, it is wise to restrict resin repairs to a shaft in the region of a bearing to those cases where the build up required is thin. It must also be remembered that the thermal expansion of resins is higher than that of metals and this has to be considered where dimensional stability is important. In the case of a very thin build up there is probably not much cause for concern.

When machines are designed, it is the mechanical properties of metals which are considered. This means that the loads involved may be quite high compared with the strength of resins since the compressive strength of a filled resin will rarely exceed 10,000 lbs./sq.in.

A proposal that moving parts may be repaired in fans and rotary compressors, especially when high tip speeds are involved, immediately causes an engineer to raise questions about stability. However, experience has shown that with proper preparation, and careful application of the resin, to ensure good adhesion, the problem of break-up with this type of repair has not arisen, but obviously there are limits to the forces the resin will stand.

There is a tendency amongst engineers to regard any resin with suspicion when there is a wear problem. The natural inclination of engineers when confronted with what is apparently a simple wear problem is to answer the problem by using a harder metal for the duty. In fact, wear problems are rarely simple and there are many cases where resins and thermoplastics perform better than metals.

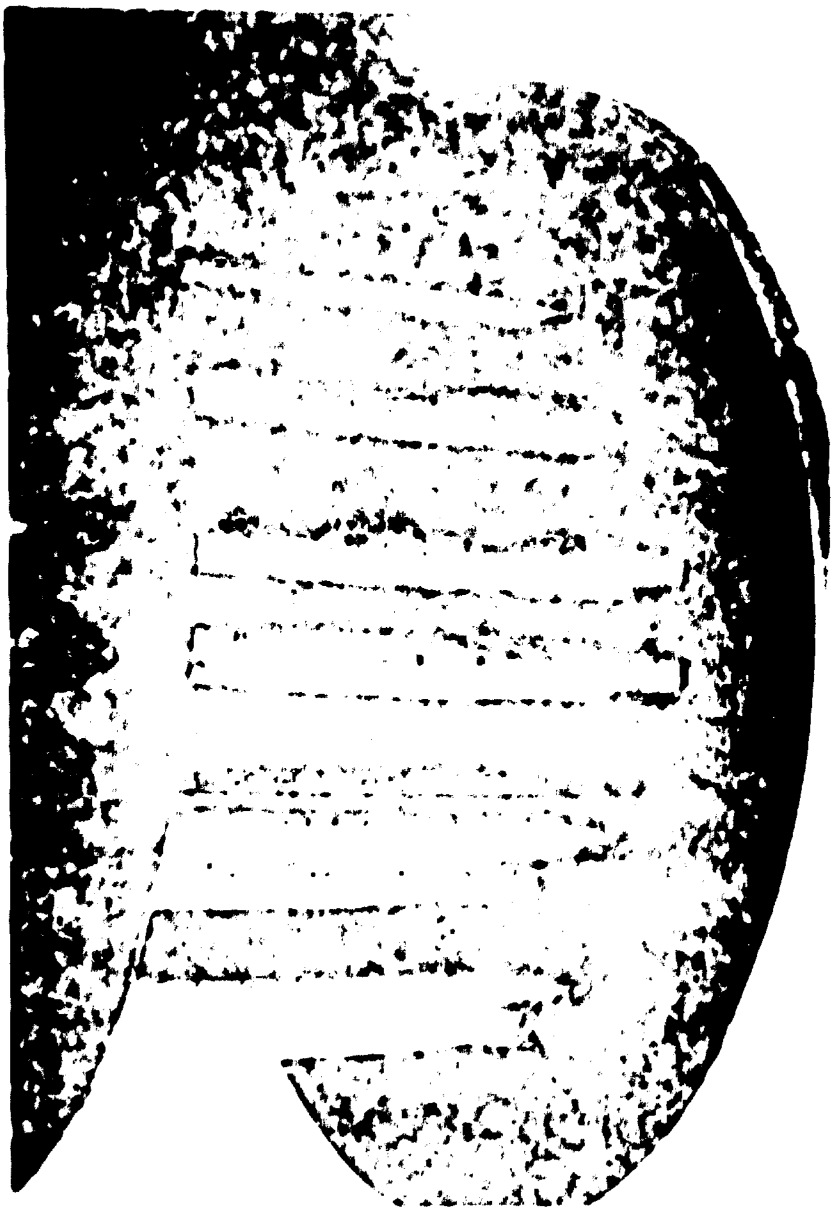

Fig. 21 Tube Bundle - Tube Plate Before Repair

Fig. 22 - Tube Damage - Tube Plate After Repair

Fig. 23 [illegible]

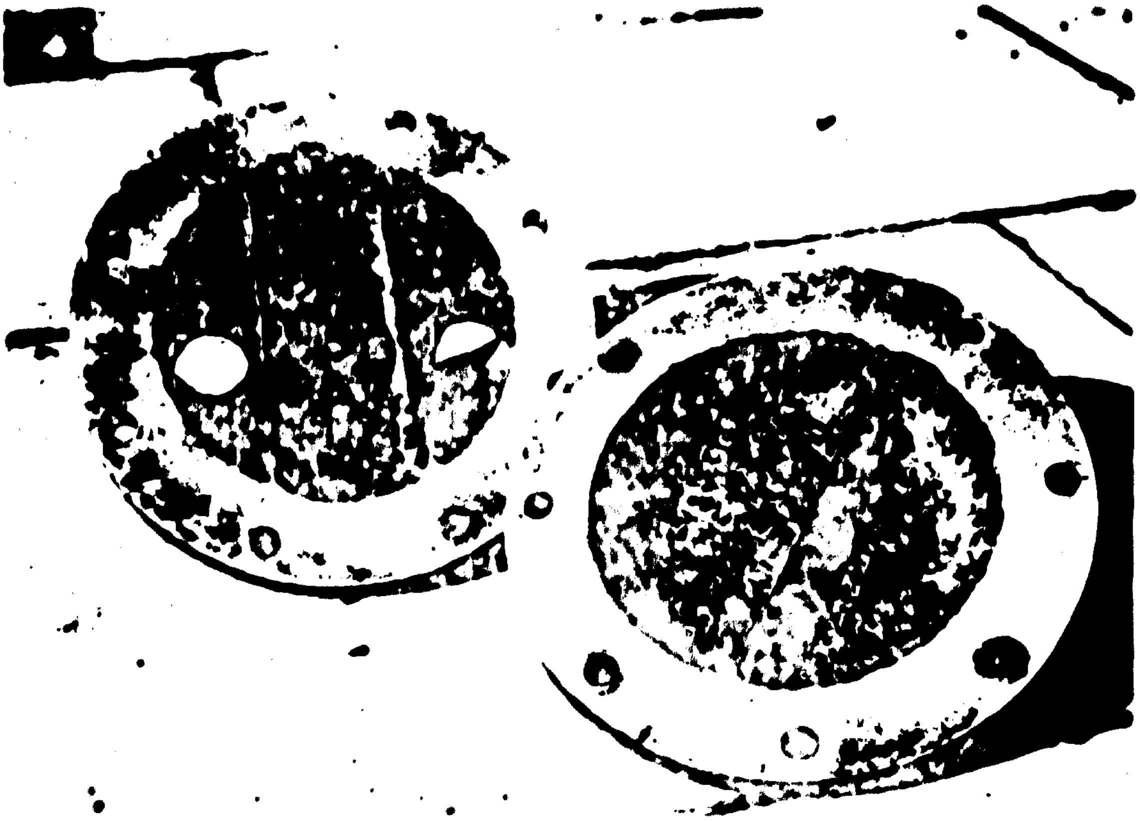

Fig. [illegible] End Cover of Water Box Before Repair

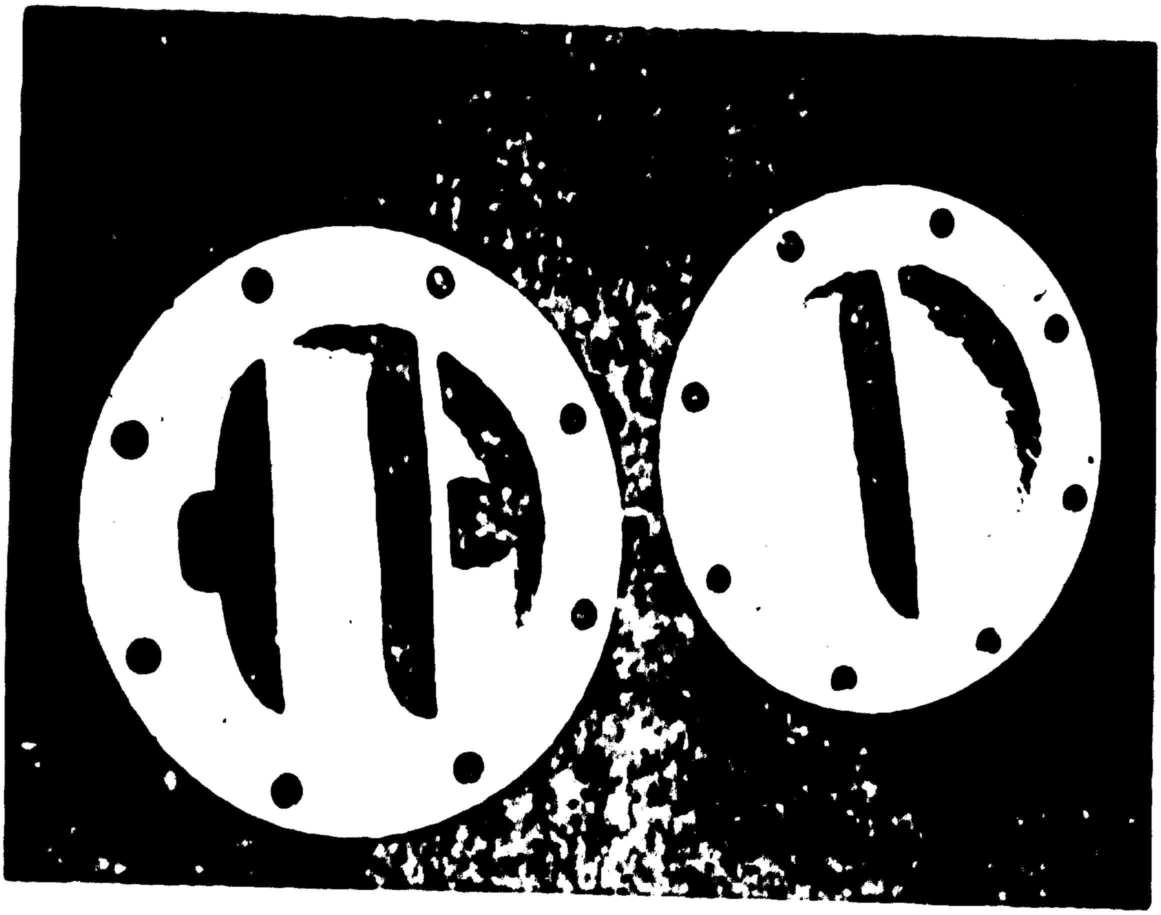

Fig. 28 End cover of water box after a year

Sometimes what is apparently a straightforward wear problem may, in fact, be a corrosion problem. Where static tests have shown the corrosion rate of steel in a given environment to be very low, or even nil, equipment has sometimes been installed, only to find that in service, failure is rapid. Upon examination, severe wear is deduced, and this assumption is often made where solids are present in a liquid or wet gas. In fact, what may have happened is that the only wear to take place was the removal of the very thin passive layer, thus allowing rapid corrosion. In this type of erosion/corrosion situation thin resin coatings (0.007-0.010 ins.) can be very effective. The circumstances under which a resin will not perform as well as metal is when the wear is due to a simple cutting action.

4.6.1 Fans

It is not unusual for fans to suffer damage at the leading edges of the blades. Such damage eventually leads to the fan going out of balance and being scrapped. If the damage is found in time, these edges can be built up with a laminate of glass and resin. The stability of resin repairs in this type of application is now well proved. The length of time which such repairs will last often depends, not upon the actual area of the repair, but on the life of the adjacent metal and it is often wise to coat the whole fan at the time of the repair. The effectiveness of thin resin coatings is illustrated by the following service experience.

4.6.1.1 Example

A large boiler plant was served by a number of induced draught fans and because of corrosion/erosion of the blades the life of the fan could be as little as three weeks and the longest life was about twelve weeks. Fans with a thin coating of resin have a life of over a year and the saving is over £8,000 per annum. Fig. 26 shows a fan with damaged blades and Fig. 27 shows a coated fan. The cost of coating a fan is about £70.

Fig. 26 Boiler Blast Fans - Damaged

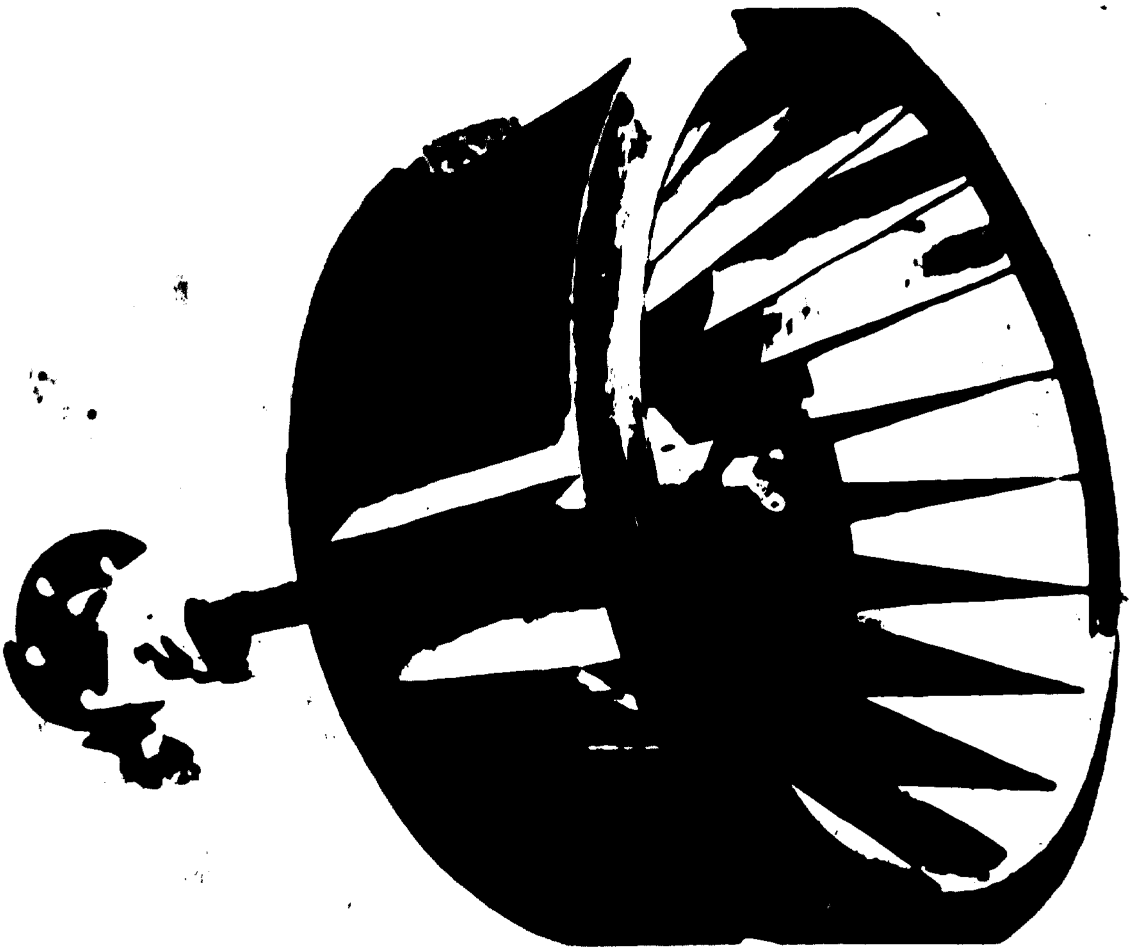

Fig. 27 Boiler Plant Fan - Coated

4.6.2 Compressors

As stated earlier, work done on compressors can vary considerably and is perhaps best illustrated by actual examples.

4.6.2.1 Example

The crankcase of a large reciprocating compressor suffered severe damage as a consequence of mechanical failure of a connecting rod. A new piece of the casing was cast from a pattern of the damaged area and this was to be fixed by metal stitching. In order to make sure that there would be no oil leaks, resin was put on the mating surfaces as the stitching was done. The work was successful.

4.6.2.2 Example

The casting forming the diaphragm in a centrifugal compressor which circulated process gas on a large olefines plant was found to be cracked. There was quite a difference in pressure on the two sides of the diaphragm and although the crack could be contained by metal stitching there was a doubt as to whether or not the stitched crack would be gas tight. Because of this doubt and the fact that a replacement diaphragm was on long delivery it was decided to make the repair gas tight by putting resin in the crack as the metal stitching was done. The whole operation was completed in about six hours and the resin cured whilst the machine was being reassembled. The repair was completely successful.

4.6.2.3 Example

In a process gas machine (centrifugal) the mating surfaces of some diffusers were found to be deeply corroded. The body mating surfaces had allowed by-passing between stages and it was this which had caused the machine to be shut down. The damaged surfaces were filled with resin which was allowed to cure. After curing, the repaired areas were dressed by hand and the surfaces finally lapped until the desired finish to the required tolerances was obtained. When the diffusers were refitted the performance of the machine was satisfactory.

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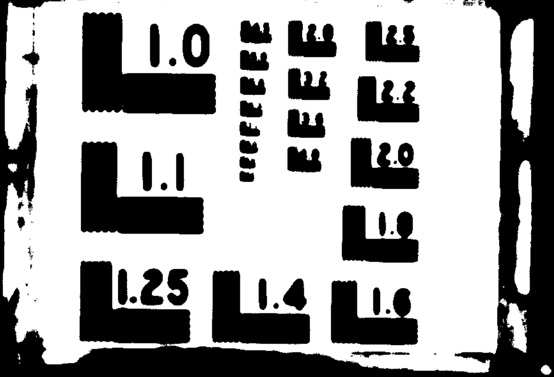

4.6.2.4 Example

The process air for a large petrochemical plant was provided by a four-stage centrifugal compressor of 6,000 HP. After the plant had been operating for about six months an examination showed that various parts of the compressor had suffered corrosion. The most serious corrosion had occurred on the shaft between the 1st and 4th stage impellers and between the 2nd and 3rd stage impellers. The shafts were machined to accommodate the labyrinth seals. The designed clearance between the seals and the shaft was 0.006 ins. but as a result of corrosion the clearance had increased to as much as 0.024 ins. and this was causing a considerable reduction in the efficiency of the machine.

Methods of repair which were considered at the time were building up the shaft (a) by flame spraying stainless steel, (b) by chromium plating, (c) by applying a filled epoxy resin, all to be followed by machining to original tolerance. It was known that the build up achieved by flame sprayed stainless steel or chromium plating would be porous and therefore, would not prevent further corrosion. Two further points to consider were (a) in order to chromium plate, the impellers had to be removed from the shaft and (b) there was some doubt about the stability of sprayed metal coatings when applied in a build up of more than 0.012". At the same time that this problem first arose (1962) it was not known to what tolerances a resin repair could be machined, or, when machining back down to metal whether a feather edge could be achieved without tearing the resin away at the break point. In order to obtain this information a test section of shaft was prepared, built up with a filled epoxy resin and subsequently machined to give a build up along its length varying between zero and 0.080 ins. on the diameter. The coating showed no sign of breaking away during machining and could be machined to the tolerances required.

Following these tests it was decided to use resin to restore the shaft. After shot blasting an excess of resin was applied, allowed to cure and then rough machined. Rough machining a build up of this kind will disclose a number of small holes in the surface caused by air trapped in the resin during mixing.

As soon as the initial machining is finished these holes can be filled without taking the rotor out of the lathe and the work of recentring is thus avoided. When the extra resin has set the final machining can be done.

Two shafts have been kept operational using this technique. In the last seven years both shafts have been repaired twice. The opportunity has been taken to compare repairs done with resin with those achieved by spraying with stainless steel. After a year's service there was little to choose between the two repairs, but from the workshop point of view the repair with resin had been done with greater ease and certainty. The original technique has also been modified. The loss of metal is normally quite irregular and with the original method of repair there was a danger of chipping at corners during the final stages of machining. Accordingly, the approach to the job is now somewhat different. Before the shaft is blasted, the labyrinth sections of the shaft are machined back below the smallest diameter, the preparation and build up then proceed as before. This means that the build up now required is much thicker. The work is illustrated in Figs. 28 and 29.

4.6.2.5 Example

This example is somewhat different from most of the previous work which has been quoted but it serves to show that once a knowledge of the materials has been gained methods of doing repairs can be developed which are a little unorthodox.

The problem concerned a high pressure reciprocating compressor on an ammonia plant. The cylinder consisted of a sleeve fitted into a water-jacket and sealed by means of O-rings. When a leak developed in the bottom seal the machine had to be stripped down in order to fit a new O-ring. This operation took four days and down time cost £1,500 per day. A method of sealing a leak without stripping the machine was required. To be effective, the repair had to last at least until the next time the machine was down for regular maintenance.

The annulus between the sleeve and the water jacket immediately above the seal was very small and it was decided to try to fill the space with resin.

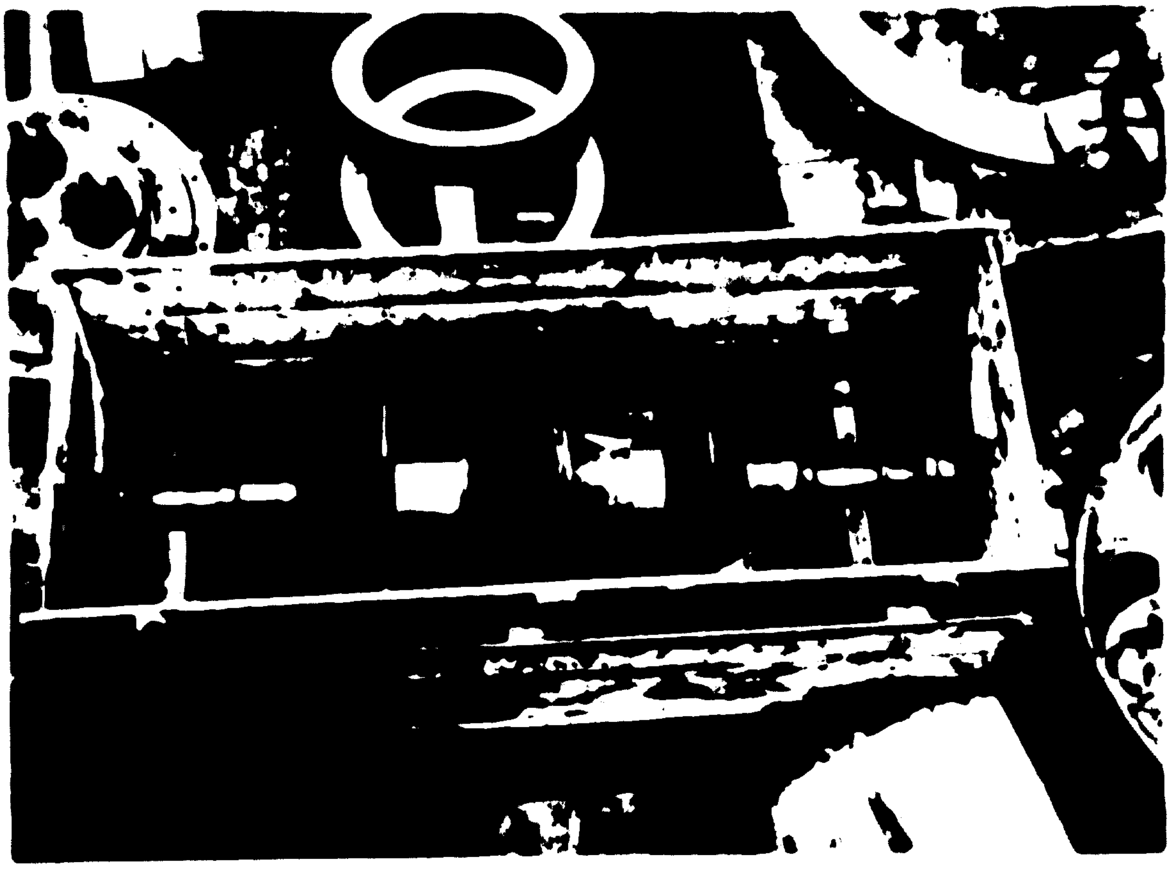

Fig. 26 Compressor Rotor

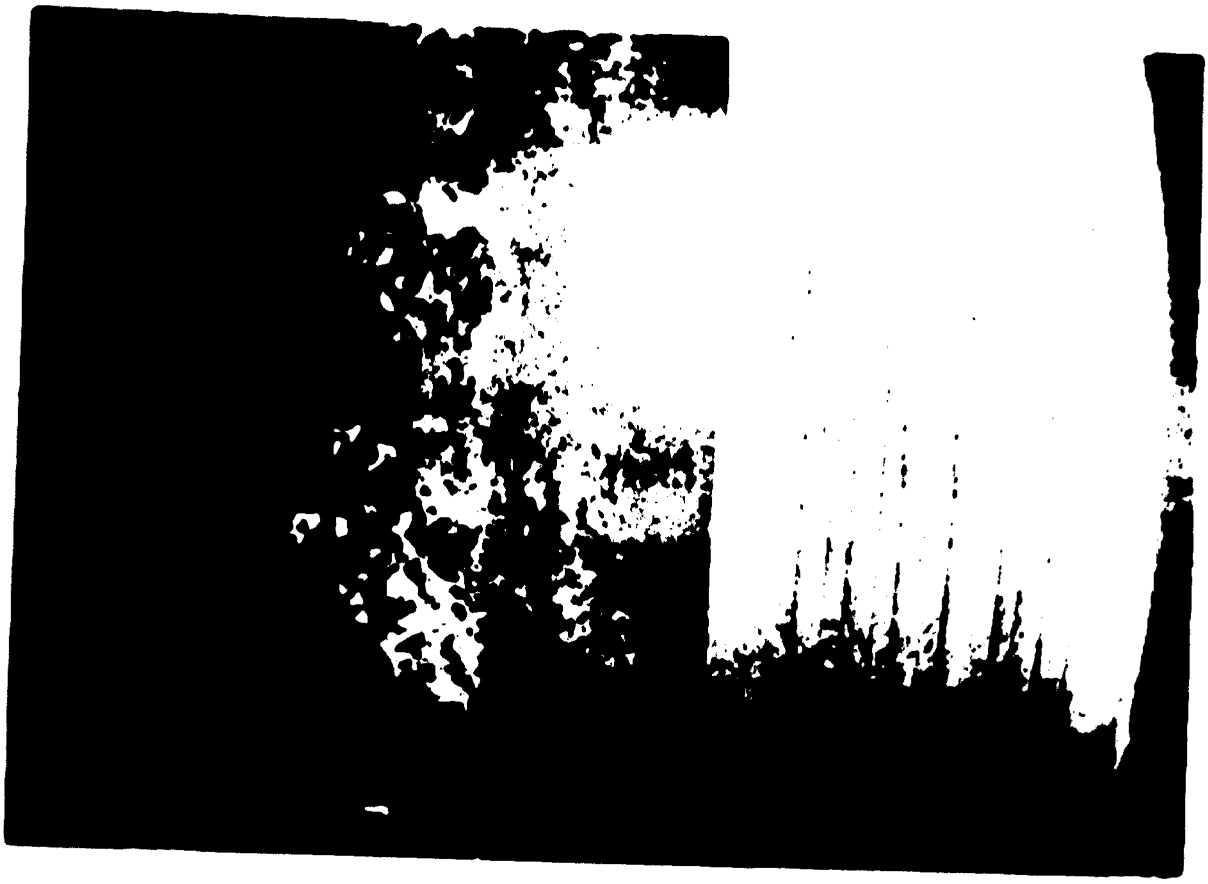

Fig. 29 Compressor Rotor - Labyrinth After Run 18

The only access was via the water connections to the jacket and the resin was fed in by means of a small diameter polythene tube fitted to a syringe. At the ambient temperature the resin was too viscous to flow along a narrow gap and it was necessary to have the machine warm so that the viscosity of the resin was reduced. This was achieved by shutting off the cooling water and using air for cooling for a short time before shutting the machine down. In addition to providing warm conditions, the method ensured that the jacket was reasonably dry before the resin was applied and the residual heat assisted in the curing of the resin.

The operation was successful and took only a few hours, saving almost four days down time.

4.7 Pipelines

The majority of pipeline repairs are relatively simple. A leaking line is shut down and resin and glass applied as a local patch or a bandage. An alternative method is to fit a steel clamp over the leak with a layer of resin between the clamp and the pipe to provide a seal. In the case of flanged pipelines there is little or no advantage to be gained by the use of this technique provided spares are available. However, the common practice in modern plants is to install all welded lines; this saves the cost of flanging and eliminates one source of leaks. Repair by welding can, of course, be done but if the pipeline carries inflammable liquid a major plant shut down may be required before the necessary clearance can be obtained. This may be equally true for a pinhole leak as for a fractured pipe.

Dealing with leaks in pipes when the line is shut down is a fairly simple matter but inevitably there is a demand that repairs be done with the line working. If, for example, the line is carrying gas at a few milliats pressure then the added difficulties are not very great, but if the pressure in the line is high then the difficulties are considerable. Nevertheless, methods have been devised to deal with such situations. These methods are described in detail under examples (2) and (3). It should be pointed out that the method described under example (3) is the subject of a patent application.

4.7.1 Example

The mild steel pipelines carrying naphtha in steam reforming plants were of all-welded construction. Some of the naphtha used proved slightly corrosive and leaks developed at welds. Repairs by welding required a major plant shut down before clearance could be obtained. Successful repairs were made in a few hours by simply taking the pressure off the lines.

The technique has also been used to forestall trouble on these lines. Non-destructive testing revealed a number of suspect welds and these welds were wrapped with a laminate of glass tape and resin. See Figs. 30 and 31.

4.7.2 Example

A cast iron pipe (15" diameter) supplied water at 75 psi to a large ammonia plant. The line was damaged, the damage taking the form of a crack and small hole. The pipe had epigot and socket joints. A spare pipe was available but to replace the pipe necessitated shutting down not only the plant immediately concerned but a large associated complex. The problem was dealt with in the following manner. A clamp was made to fit round the pipe with soft rubber jointing material at the edges of the clamp. To prevent the clamp being subject to the full line pressure a small bore pipe fitted with a valve was let into the clamp to take the leaking water away. The clamp was fitted around the main pipe and a laminate of resin and glass was then built up over the clamp and on to the water main. When the resin had cured the valve on the pipe from the clamp was closed. The laminate applied was sufficient to withstand the working pressure of the water in the main.

4.7.3 Example

The problems described in this example occurred on a cross-country pipeline carrying ethylene from the manufacturing plant to a large petrochemical complex 120 miles away. The line is 8" diameter and is designed to operate at 1400 psig. At intervals of approximately ten miles there are stop valves each with a bleed line that enables a given section to be blown down. When this is

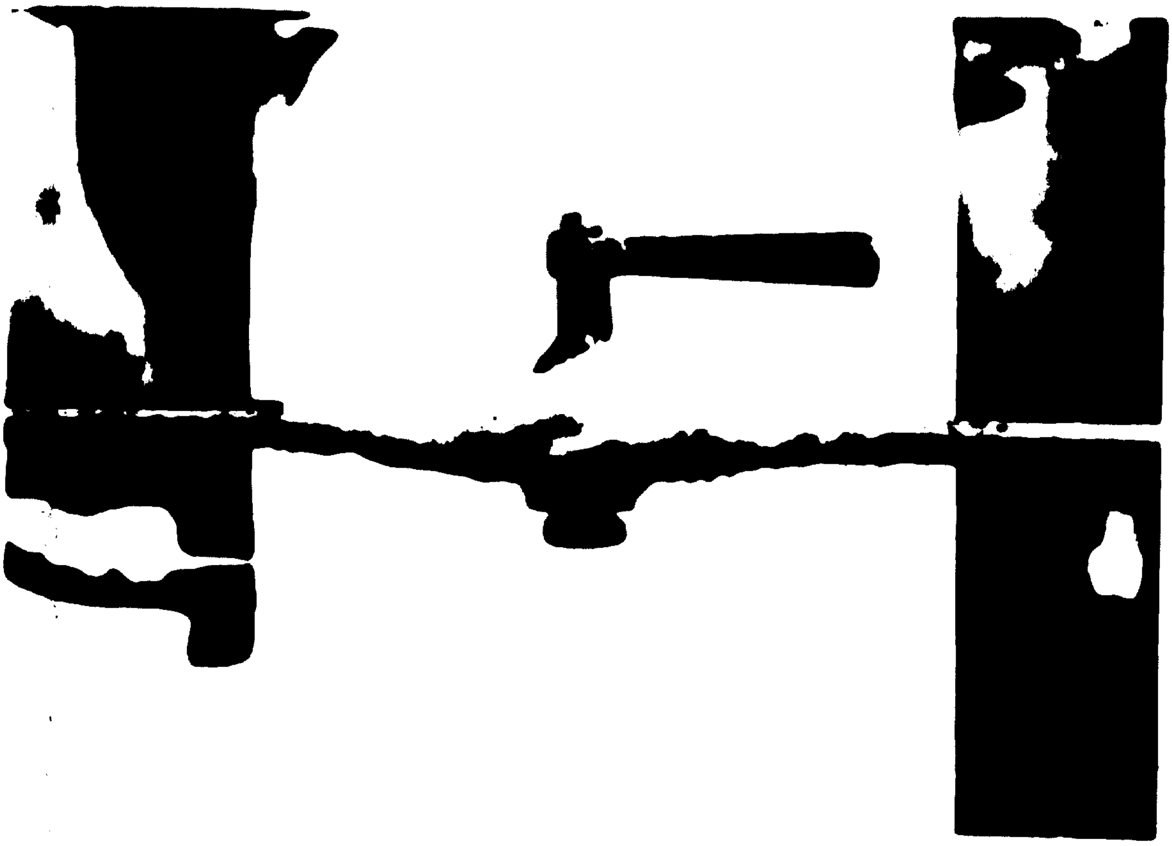

Fig. 30 Pipeline wrapped

Fig. 31 T-Piece wrapped

done, the contents of the section of line are burned in a transportable flare stack. Obviously the line was designed so that repairs could be executed, it being possible to blow down one or more sections of the line. Nevertheless, this is undesirable on at least three grounds:

(1) The ethylene in any particular section would be lost. This is a considerable loss since the value of ethylene in a section is about £6,000.

(2) The setting up of a flare stack, possibly in a remote location, is inconvenient and burning the ethylene may be a nuisance.

(3) There would be an interruption in the supply of ethylene to plants at the receiving end. Shutting down the line, doing the maintenance work and recommissioning the line could obviously be a lengthy business and the plants depending upon the supply would suffer equivalent down time at enormous cost.

Leaks have developed at four locations and a technique has been developed for dealing with these leaks without shutting the line down. Leaks in three locations were quite different to each other but all have been dealt with by variations of one technique. It would, of course, be hopeless to attempt to stem a leak at these or similar pressures simply by covering with filled resin or by means of a resin/glass laminate, since the internal pressure would speedily build up to a point at which gas would find its way through the resin whilst it was setting. In simple terms the technique which was adopted is as follows.

A steel box was fitted around the leaking part, a joint being made with resin and whilst the resin was setting the leaking gas was bled through both resin layer and the box. After the resin was cured the bleed path was sealed. The box was so designed to withstand the burst pressure and to ensure that the resin bond forming the seal was in shear. In shear, provided that proper preparation has been done, it is possible to obtain bonds with a strength of about 1,000 lbs./sq.in. and the box was designed so that the minimum leak path had adequate resistance to the internal pressure. The technique is best illustrated by describing the three cases in detail.

(1) The first leak to be dealt with was done with the line pressure at 600 psi. It occurred on a flanged joint between a bleed line and a main valve. The arrangement is shown in Fig. 32. It can be seen that the shape of the assembly was complex and a casting of the relevant portion was obtained using a silicone casting rubber. From this a plaster positive (Fig. 33) was made and used to check the dimensions of the box. A steel box (Figs. 34 and 35) split into two halves was designed to contain the pressure. To provide a route for the bleed line a high pressure compression fitting was welded to the box.

In preparation for the actual repair the area to be treated was grit blasted using portable blasting equipment. Air was supplied from a mobile compressor. The next step was toseal between the faces of the flanges but to leave a bleed in the appropriate location by means of a 1/16" diameter p.t.f.e. (polytetrafluorethylene) tube properly located to fit the corresponding position in the metal box. In order to achieve this effect and because the position of the leak was unknown, a leakage path to the p.t.f.e. tube was provided by winding a string loop between the flanges and up to the raised joint face which traps the gasket. The space between the flange faces and up to the loop was filled with a quick setting epoxy mortar. After this resin had set a check test was made to establish that the bleed was functioning properly and there would be no leak and build up of pressure in the resin to be placed in the steel box before curing was complete. At this stage the interior of the sections of the box and the surfaces of the flanged fitting were heavily covered with an epoxy resin mortar, care being taken that the amount of mortar was in excess of that required to fill the gap between the flange fitting and the box. Accurate fitting of the upper portion of the box was a somewhat delicate operation in that the p.t.f.e. tube had to be guided through the fitting attached to that section. The fitting completed,

Fig. 32 Valve on Ethylene Line - General Arrangement

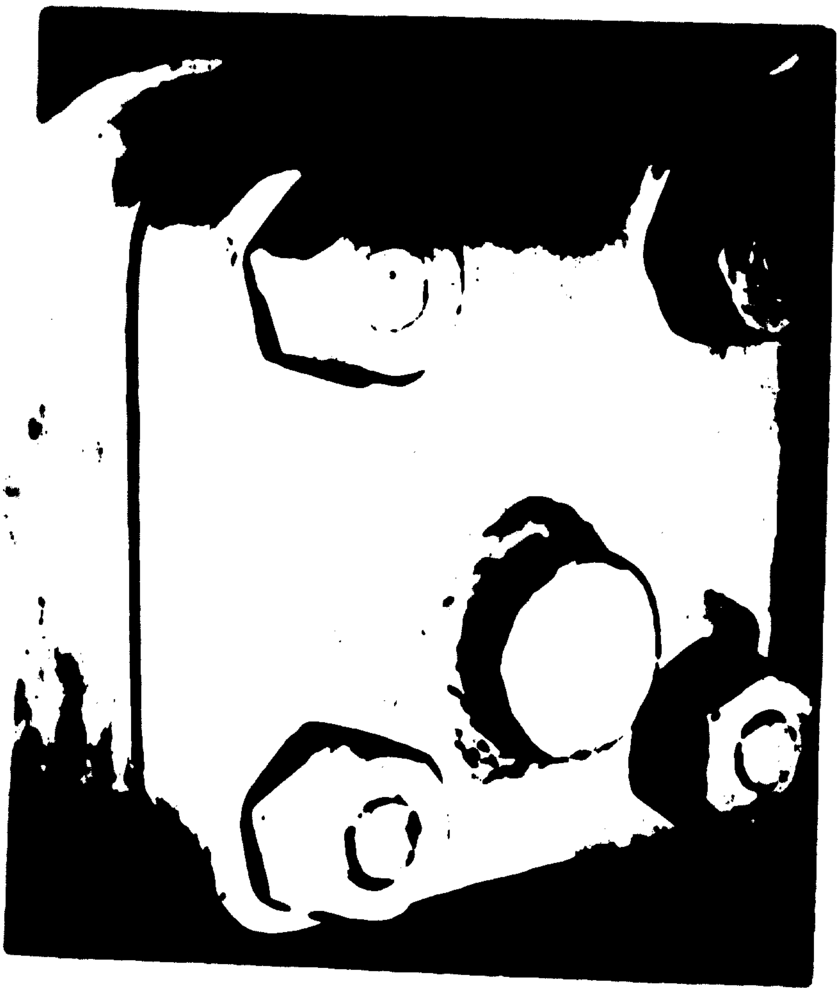

Fig. 33 Plaster Cast of Part of Valve

Fig. 34 Steel Box for Repair of Leak

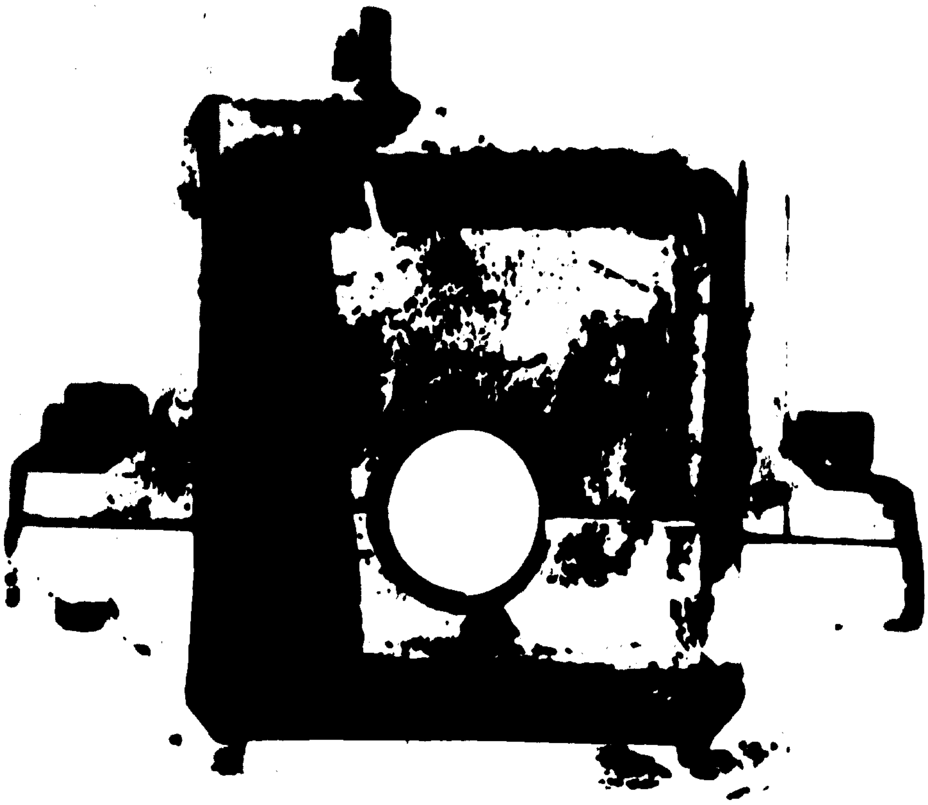

Fig. 35 Steel Box for Repair of Leak

the sections were bolted together and drawn tightly against the valve body by means of a suitable yoke (Fig. 36). The assembly was left for 72 hours for the resin to set and cure, when a check test showed that the leakage was now controlled and issuing entirely by way of the p.t.f.e. tube through the closure fitting. The p.t.f.e. tube was withdrawn and the closure fitting sealed. The assembly was tested for leaks with soapy water and found to be tight.

(2) The bleed line to a main valve at another location was of welded construction and welded into the valve body. A sizeable leak developed in the weld. In this case a p.t.f.e. tube was fixed over the leak with the aid of a temporary clamp and quick setting resin. After the resin had set the temporary clamp was removed. A box, in principle similar to the one described above, except that the inside of the box in this case was shaped to accommodate the resin holding the bleed path in position, was then fitted. The line pressure during this work was 1,350 lbs./sq.in. The leak was effectively sealed.

(3) At some points in the line a 3" by-pass pipe is fitted. The 8" line is all-welded construction but the 3" line contains flanged joints at valves. The joints are made with metal O-rings. Up to the first valve the 3" line is at pressure all the time. A leak developed in such a flange joint. Establishing a bleed path in this case was a particularly difficult operation. The design is illustrated in Fig. 37. In order to fit the sections of the bleed path, bolts had to be removed in pairs; whilst this was done, a heavy clamp held the flanges together. When the bolts were refitted care was taken to ensure that there was not a leak path between the joint and the bolt holes and the whole of the space between the bleed path and the outside of the flange filled with resin. Before this resin was subjected to pressure a clamp was fitted right round the flanges as shown in Fig. 38. The work was done at 1,350 psig.

4.8 Glass Enamelled Equipment

The use of vitreous enamel for the protection of cast iron against corrosion is a well-known and useful method. The chemical conditions which it will withstand are many and varied; however, it is prone to damage by mechanical

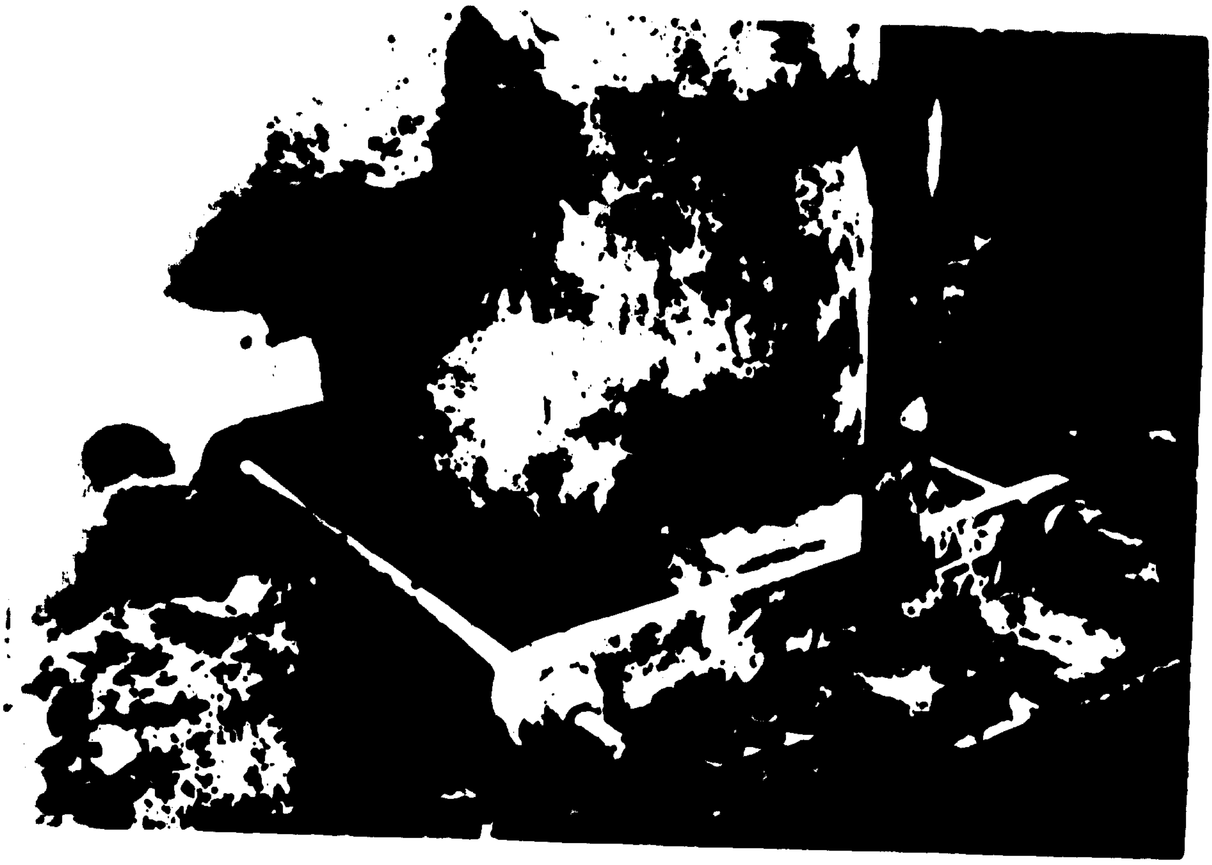

Fig. 35 Completed Repair

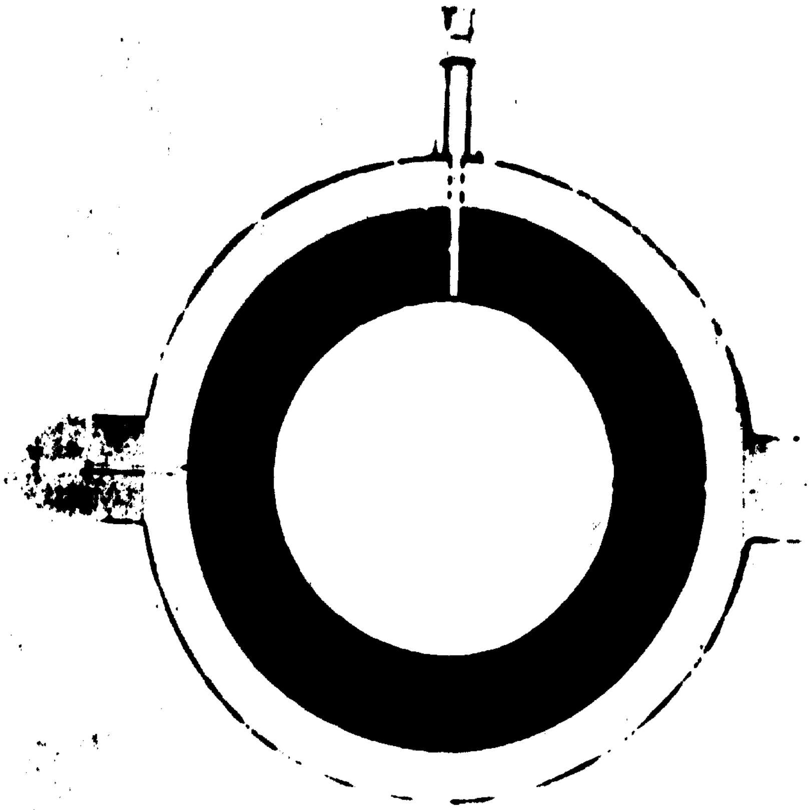

Fig. 37 Diagram of Repair to Flanged Joint

or thermal shock and repair is not easy. Small pinholes can be dealt with by drilling and tapping and then fitting tantalum or p.t.f.e. plugs. For larger areas of damage, use of resins provides the only practical way of dealing with the situation. In many cases, following damage to the glass lining, there is also loss of metal and this has to be replaced. There are two methods of dealing with gross damage. The easiest is to apply a simple resin patch of either resin mortar of a laminate. Adhesion to glass is difficult to obtain and the best resin for the purpose is epoxy. However, this will not withstand all the chemical conditions encountered in the repair of this equipment and a useful technique is to use epoxy resin for replacing lost metal and obtaining a bond to the glass. This resin is then overcoated with another resin of more suitable chemical resistance. A second method involves the use of preformed sections made of a laminate of phenol formaldehyde resin and asbestos. These preformed sections are available commercially in a variety of shapes and sizes and are meant to be cemented into branches, manholes etc. with an appropriate resin cement.

4.8.1 Example

The bottom section of a chlorinator on an acrylonitrile plant failed in service. The section was made of cast iron, glass enamel lined, and failure had started through cracking of the glass lining. The duty of the vessel was severe, involving exposure to concentrated hydrochloric acid in the presence of chlorine at temperatures up to 115°C; after failure of the lining serious corrosion of the cast iron had occurred. A new section was not available and repairs were attempted with resins.

The first attempt was made with an epoxy resin cement mortar filled with silica flour. The adhesion obtained between the rendering was satisfactory but the duty proved too severe for the cement and it failed after ten days.

It was known that a cement based on phenol formaldehyde resin would probably have adequate chemical resistance but it was also known from past experience that renderings with a phenol formaldehyde cement direct onto steel or glass had not been successful owing to poor adhesion. Therefore, a composite lining was tried. A rendering of epoxy resin cement was used first and when this had set a render of phenol formaldehyde cement was applied. This system appeared satisfactory but failed after five weeks in service. The reason for the failure, which was local rather than general, was not apparent but it is probable that it cracked because of differential expansion.

The system was repeated and the vessel put into service once more. In that way the plant was kept in operation until a new glass-lined section was obtained.

This work was done in 1960. If a similar situation arose today there would not be the same need to use a duplex system. The bisphenol polyester resins now available would be suitable for this type of duty.

4.9 Repair of Rubber Lined Equipment

Local damage to rubber lined equipment in chemical plants is often followed by loss of metal, in fact, the damage is often discovered when the steel is holed. In the cases where there is damage to the steel it is not possible to simply apply a rubber patch by conventional methods. If welding is carried out to repair the steel, further damage is done to the surrounding rubber by the heat of welding. The difficulty is overcome quite simply by replacing the lost metal with a cement based on epoxy resin. This can then be dressed so that a smooth contour is obtained and the normal rubber lining technique used for patching the rubber.

4.10 Repair of Electrical Equipment

Resins are electrical insulators and, therefore, can be used for the repair of insulators made of other materials.

4.10.1 Example

The starting equipment of winding gear in a mine shaft was put out of action because an insulator had been badly damaged by arcing. The compressed fibre insulator was built up with epoxy resin and the winding gear was operational in eight hours.

4.11 Repair of Porous Castings

Porous castings can be made non-porous by treatment with resins in three ways. The method adopted depends upon circumstances, the material available, the equipment available and the shape and size of the casting. The methods available are:

(1) Vacuum impregnation

(2) Pressure impregnation

(3) Heating of the casting to make the air in the pores expand. Whilst the casting is hot it is placed in a bath of resin. As the casting cools, the resin is sucked into the pores.

Although these methods are available, it is not suggested that castings known to be porous can be accepted at purchase. But, when castings prove to be porous after a period of service, the techniques are satisfactory for emergency repairs.

4.11.1 Example

The casting forming a bearing casing on a turbo blower proved faulty in service. The casting was porous and there was a continuous leakage of oil. A replacement casting was on extended delivery. The process used was as follows:

(a) The casting was heated to 150°C.

(b) Whilst the casting was hot it was filled with a resin varnish, which was left in until the casting was cool enough to handle.

(c) Surplus varnish was washed off the machined surfaces with solvent.

(d) The casting was stoved at 150°C to remove solvent and to cure the resin.

(e) The process (a) to (d) was repeated.

After the treatment a paraffin test failed to detect any sign of porosity.

4.11. 2 Example

A phosphor bronze casting forming a cylinder in a methanol booster pump was found to be porous in service. The duty was severe, a test pressure of

290 atmospheres being required. The casting was filled with an epoxy resin of low viscosity and a temporary closure fitted. A pressure slightly in excess of the test pressure was then applied. The pressure was maintained for two hours. After which time, the bulk of the resin was removed and resin which had been forced into the pores was allowed to cure. The casting was successfully sealed.

4.12 Repair of Concrete, Replacement of Mounting Blocks for Machines, Grouting Machines

Bonding of new concrete to old concrete has presented a problem for many years. For simple applications such as repairs of floors, satisfactory results can be achieved if the surface of the old concrete is roughened and a new concrete is placed on top to a minimum thickness of 2-3". The standard of adhesion obtained in this matter has not been considered satisfactory for structural application. If thin screeds were placed they would break up under high loads or at edges under normal traffic. Use of epoxy resin to promote a bond overcomes this difficulty. The procedure is quite simple. All loose material and dirt is removed from the surface of the old concrete, the surface is then coated with an appropriate epoxy resin. The new concrete can be placed immediately, or up to four hours after priming the concrete with resin. When the concrete has cured, the bond between the old and new concrete should be at least as high as the strength of the concrete. This application always arouses sceptic in those who are not familiar with the technique. The system is easily proved, by taking a concrete beam, e.g. 5 ft. long, 1 ft. deep and 6" wide, and breaking it in half. The end of one half of the block can then be treated with resin and then shuttered so that new concrete can be poured to remake a block of the original size. After the new half of the concrete has had time to cure the block should be broken again. It will not break at the actual joint. Even using a hammer and chisel it will be very difficult to part the concrete at the glue line.

The technique described above permits repairs to be made to structural concrete with a fair degree of certainty but does not shorten the time required for concrete to develop reasonable strength. When it is essential for loads to be applied quickly, epoxy resin mixed with sand and gravel can be used en masse to replace damaged concrete. Mixes of this type have been prepared and used which have developed a strength of 10,000 lbs. in twenty-four hours. A typical graph showing compressive strength against time for an "epoxy resin concrete" is shown in Fig. 39.

In addition to the rapid cure which can be obtained with an "epoxy resin concrete", it is possible for other advantages to be gained by its use in place of Portland concrete. The reason for the repair may be attack on the original concrete by chemicals and epoxy resin concrete may have much better resistance. In some cases, e.g. wet ammonium nitrate, chemicals not only attack concrete but completely inhibit the cure of freshly placed concrete.

The cost of an epoxy resin based concrete is very high (£3-£8 per cu.ft.) and its use in large quantities will obviously be severely restricted.

However, there is one field where advantage gained in reducing down time far outweighs the increased material costs, and that is in the mounting of machines.

The need to remount machines can arise for several reasons; poor grouting, deterioration of concrete due to oil contamination, slight movement of support blocks causing misalignment, break up of concrete plinths under the applied load.

Methods of mounting machines vary, but using conventional materials all the methods commonly used in the past take considerable time, mainly due to the period required for normal concrete to cure. A typical concrete used for making machine mounting blocks will take three days to attain a strength of 1,500 lbs/sq.in In addition to the time required for concrete to gain strength there is the time required to finish concrete pads. They cannot be cast level and true to the tolerances required for the mounting of sophisticated machinery. The normal procedure is to achieve the finish by grinding. This in itself is a long and

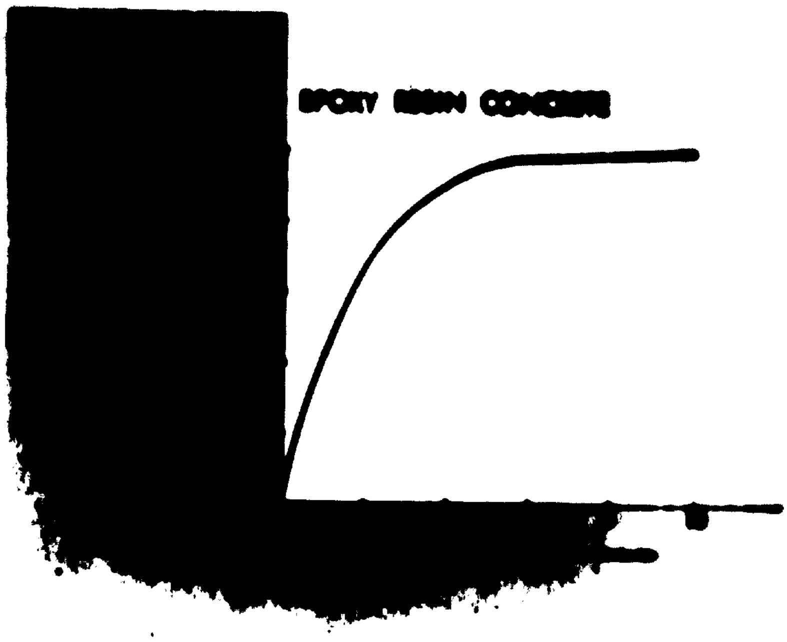

Fig. 39 Graph showing Increase in Strength of Epoxy Concrete with time

tedious process but can start only when the concrete has developed a reasonable strength. Using epoxy resin these limitations can be overcome. This is illustrated in examples 4, 5, and 6.

4.12.1 Example

Part of the floor of a transformer house was found to be slightly below the required level. To break out the floor so that a thin screed could be laid was undesirable for two reasons (a) the time involved and (b) the problem of dust affecting switch gear. The original floor was coated with resin and a thin screed of concrete applied. This repair has been satisfactory during the past 3½ years in spite of the fact that it is frequently subjected to heavy loads.

4.12.2 Example

Concrete bases prepared for a number of vessels and machines, including a large compressor, were damaged. Water was left in the cavities which had been preformed for the holding down bolts. The water froze and the concrete cracked. The normal procedure would have involved breaking out the concrete and recasting - a time-consuming and expensive process. Instead, only the concrete which had broken away was removed, the exposed surface treated with resin and a relatively small quantity of concrete recast. The machines and vessels subsequently mounted have been in operation for a number of years and no trouble has been experienced.

4.12.3 Example

A prilling tower on an ammonium nitrate plant was constructed of reinforced concrete and lined with aluminium. The hopper section at the base of the tower was also of reinforced concrete but lined with stainless steel. The purpose of the aluminium and stainless steel was to protect the concrete from attack by ammonium nitrate. In service the stainless steel was damaged and in time the attack on the concrete was fairly extensive. All the damaged concrete was removed and replaced with epoxy resin mixed with sand and gravel. The scale of the work was large and casting took place round the clock. The use of resin, although expensive, showed considerable advantage. Even with the most rigorous cleaning of the surrounding area, one could not be certain the Portland cement would remain uncontaminated by ammonium nitrate, a trace of which would arrest the cure of ortland cement. The other advantage was that twenty-four hours after the poxy resin concrete was cast it was possible to start relining, and by the time he lining operation was finished, the hopper was strong enough for the tower to e recommissioned.

4.12.4 Example

Six large centrifuges [redacted] were originally mounted on steel locks on top of concrete plinths. There were holding down bolts at the four orners of the machine. The rim of the machine was grouted in with sand and ortland cement. Mechanical trouble was experienced with these machines in service, ttributed in part to the method of mounting.

The machines were removed for mechanical overhaul and Fig. 40 shows he state of a plinth at this stage. It was specified, for replacing the machines, hat the whole of the space under the machine, an area of 5 ft. x 4 ft., should be illed with grout. Because of process limitations, it was highly desirable that he machine should operate 24 hours after placing the grout. This would have been uite impossible with a sand cement grout since it would not have gained sufficient trength to withstand the vibration.

Use was made of a ramming mix based on epoxy resin filled with sand nd pea-sized gravel. The skirting of the machine was sealed with a mix slightly icher in resin. Six machines were remounted in this way and some were operated fter 24 hours. Fig. 41 shows the base of one machine immediately after grouting. his work was done in 1967 and all machines are still in service. Fig. 42 shows general view of the machine (1970).

4.12.5 Example

A very large reciprocating compressor on a CO_2 plant had to be mantled because of deterioration of the foundation. It had been in position for out 30 years. The top few inches of the old foundations were broken out. Normal ocedure would then have been to reform the foundation blocks and when this had red set up concrete pads to receive the steel support blocks. A very lengthy ocess!

Fig. 40 View of Plinth after Removal of Machine

Fig. 41 Centrifuge - Remounted

Fig. 42 Centrifuge - General View

Instead of the above procedure the 5" steel blocks were set up on filled epoxy resin pads cast directly onto the freshly broken concrete. By casting the bulk of the epoxy resin pad, allowing it to partially cure and then bedding the steel blocks with epoxy mortar, it was possible to set the steel blocks level (± 0.0002"). The working time to set up 26 blocks was 12 hours. The crushing strength of the epoxy resin mix used was 10,000 lbs. after 24 hours.

Fig. 43 shows a general view of the mounting blocks. Fig. 44 shows a close up of a block. Fig. 45 shows a view of the machine.

4.12.6 Example

A number of free piston engines operated on an olefines plant. The machines were mounted on concrete plinths. A general view of a machine is shown in Fig. 46. The support frame and plinths are below floor level. Because of the way in which this type of machine operates, the concrete plinths on which the free piston engines are mounted are subject to a very heavy pounding and have a limited life. Prior to 1966, it was customary to remove the damaged concrete (usually 2"-4"), cast new concrete and, when this was cured, grind until it was flat and at the required level. This procedure took at least 4 days. Using epoxy resin for the repair it has been possible to set up the machine frame, level and to datum, in 24 hours. The work is done in two stages. The plinths under repair are built to within 1/8"-1/4" of the final level using a sand filled epoxy resin. When this has partially set (4-6 hours) the steel blocks are bedded on epoxy mortar and set level and to datum. Assembly of the machine can start next day.

At least six machines have been remounted by this method and all are satisfactory in service.

5. REPAIRS USING SODIUM SILICATE

5.1 Materials

Soluble sodium silicates have been made for over a hundred years and find numerous applications in industry. Uses are many and varied ranging from the preserving of eggs to the manufacture of fireclay. Sodium silicate is the

Fig. 43 Compressor - General View of Mounting blocks

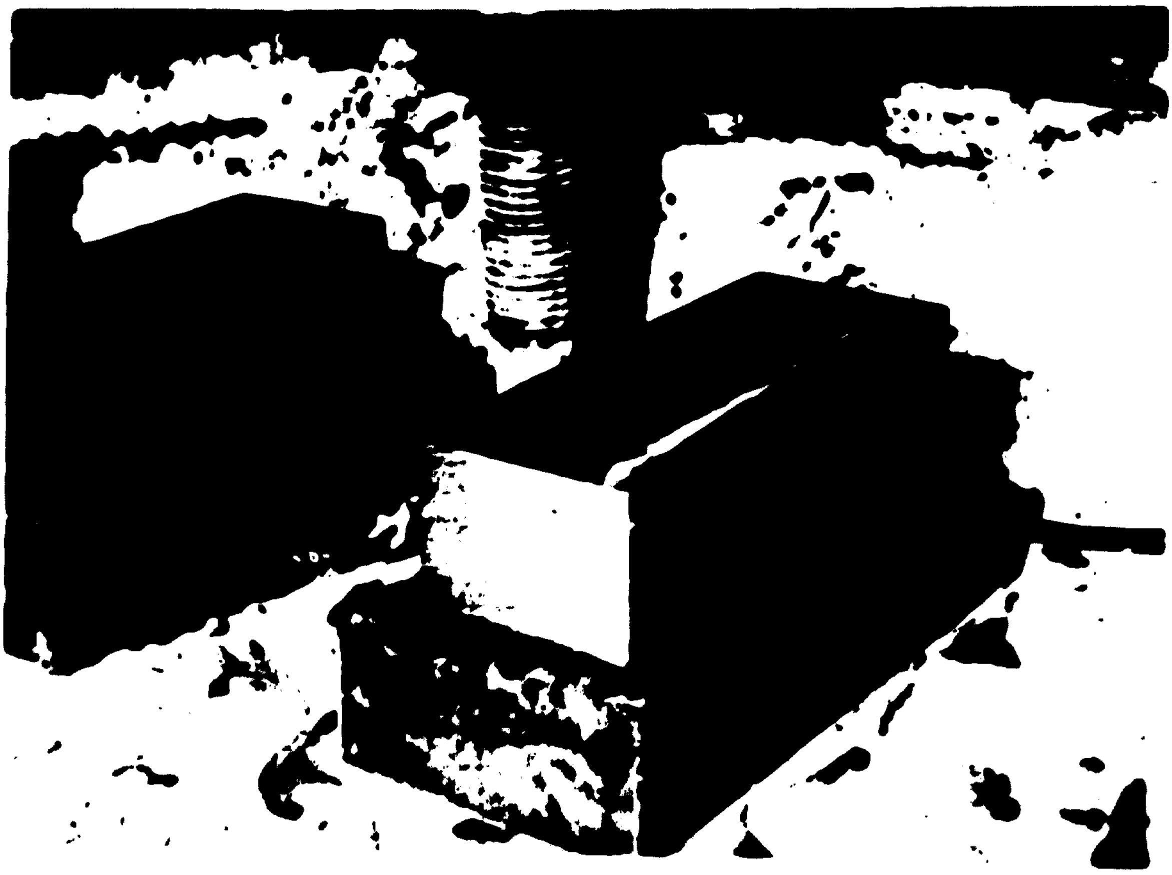

Fig. 46 Compressor - Details of Mounting Blocks

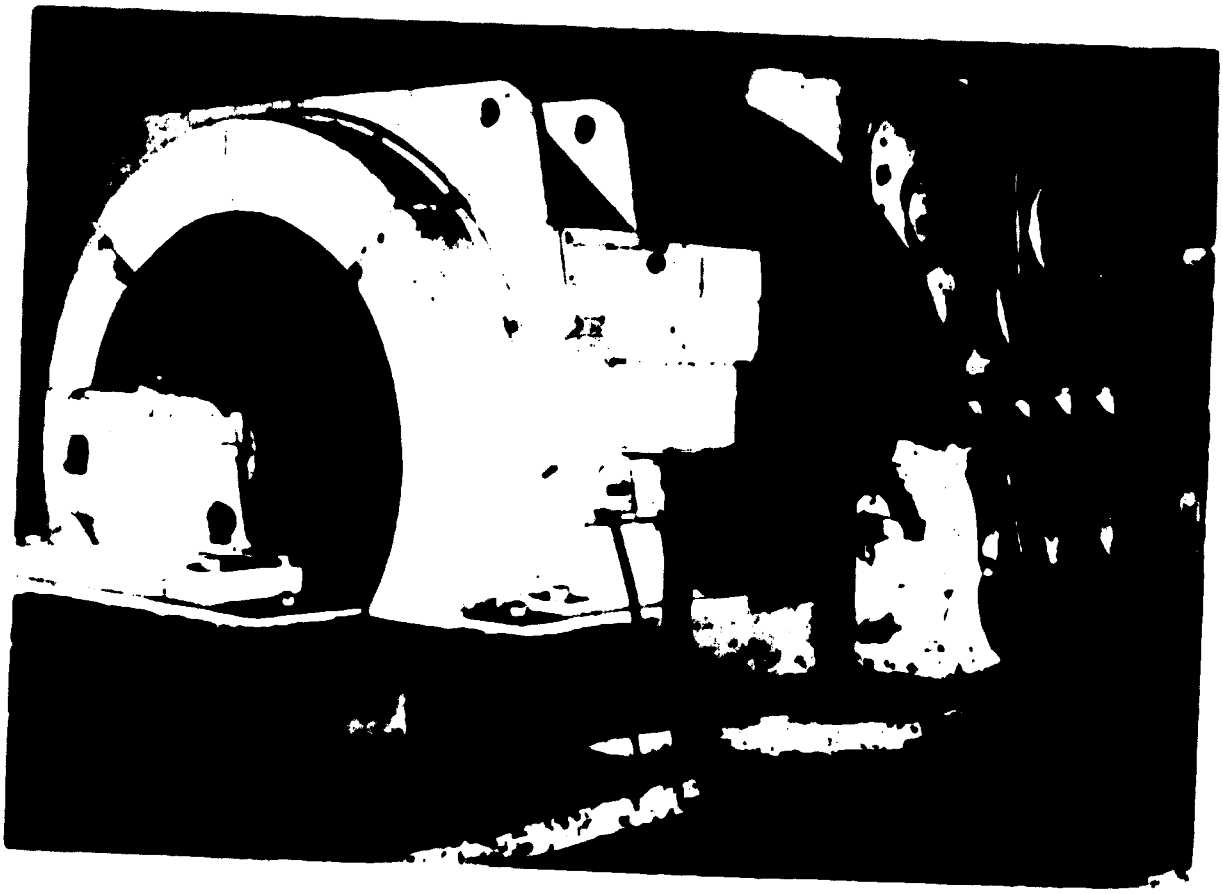

Fig. 45 General View of Compressor

Fig. 46 Free Piston Engine

basis of one of the first acid resisting cements. Like resins, sodium silicate can be mixed with fillers to form a mortar. It can also be used for impregnating a reinforcing material such as a glass, but more usually asbestos cloth or paper are used.

Sodium silicate solutions can be made to gel and set into a hard mass either by the action of heat or chemical hardeners. Two chemicals used for this purpose are sodium silicofluoride and ethyl acetate. Heat will accelerate the chemical reaction. The reaction is also catalysed by acids, an important point to remember when it comes to applications since the presence of acid may cause a silicate to flash set. When any cement flash sets the chances of getting good adhesion are poor.

Sodium silicate which has just gelled is quickly destroyed by water, steam and alkalies.

5.2 Techniques

Although Silicate cements are excellent for bonding bricks and other ceramic units for acid resisting work it is rare that they are used in the form of a mortar for emergency repair work. The shrinkage on setting is too high and the level of adhesion obtained to steel is somewhat doubtful.

The main use is with asbestos cloth or paper in a laminating technique. It can be used in this form to seal cracks in chemical stoneware, glass, mild steel, stainless steel and aluminium. The laminate is applied by a simple bandaging technique or as a sealing layer under a steel clamp.

Most applications are limited to simple sealing and pressures in the applications are not normally high. Usually, it is sufficient if the surface is clean and grease-free.

5.3 Equipment

Very little equipment is required. Quantities mixed will generally be small and thus, apart from measuring equipment to control the mix, only spatulas, mixing tins and brushes are necessary.

Costs

The value of materials used in most repairs is very low. The cost of sodium silicate is about 1/- per lb. and that of asbestos about 5/- per lb.

6. APPLICATIONS AND CASE HISTORIES

6.1

In the section on the use of synthetic resins, reference was made to the effect of temperature. In this connection, it was stated that 150°C was about the practical limit. Mention was also made of the limits of chemical resistance and in this respect none of the resins are suitable for use in the presence of nitric acid above about 50% concentration. It is extremely convenient, therefore, to have a material such as sodium silicate, which can be used at temperatures as high at 900°C and which is quite resistance to concentrated (98%) nitric acid. It is in these rather special fields that the material proves most useful. Typical applications are the sealing of leaks in aluminium pipes, stainless steel pipe and glass pipe used for nitric acid. Another application is sealing gas mains carrying nitrous gases at 700°C.

6.1.1 Example

A plant for the concentration of nitric acid is constructed almost entirely of glass. Inevitably, there are occasions when some of the glass suffers mechanical damage. Fig. 47 illustrates a 24" diameter glass still used for concentrating nitric acid. This still works under vacuum. A section was damaged and no replacement was available. A repair has been made with sodium silicate and asbestos paper. This repair is typical of many others and it is not unusual to get a year's life from such a repair.

7. REPAIRS USING RUBBER COMPOUNDS

7.1 Materials

There are available, compounds based on both natural and synthetic rubbers which are useful for emergency repairs especially where steam leaks are concerned. Furthermore, the properties of these compounds are such that steam leaks can be repaired without shutting down. None of the other materials mentioned in the earlier parts of the paper are suitable for this type of work

Fig. 47 Nitric Acid Plant - Repair of 24" Glass Still

The compounds supplied ready for use are based on uncured rubbers. These compounds when heated almost melt and can then be extruded into very small gaps. On further heating the compound sets to form a hard but reasonably elastic material. If high operating temperatures are involved (about 200°C) the compound will lose its elastic properties.

7.2 Technique

The principle consists of injecting the compound in its uncured state into a leak. The compound is restricted to the area of the leak and retained there during the curing period by mechanical means. In order that the compound will flow it needs to be injected at temperatures above 115°C. If the leak is on a cold line the gun can be heated by blow lamp. A clamp of some sort is placed round the leak and the compound is injected either through an injection point fitted in the clamp or, in the case of a flanged joint, through a special bolt. The compound takes about 30 minutes to cure. If the pressure behind the original leak is not too high the clamp may be removed after the compound has cured.

7.3 Equipment

The equipment required depends upon the type of work to be done and the type of clamps required but, of course, an injection gun is essential. Adaptors, specially drilled nuts and clamps will also be required. Complete kits are available from manufacturers of the sealing compounds and the charges are quite modest.

8. APPLICATIONS AND CASE HISTORIES

As already mentioned, one of the main applications of this technique is for the sealing of steam leaks. It is particularly useful for sealing leaks in flanged joints in steam lines. It may be used also for sealing leaking glands on valves. In addition to the use on steam lines the method can be used to seal leaks on pipelines carrying chemicals to which the compounds have adequate resistance. One compound available is particularly suitable for hydrocarbons.

8.1 Example

There is little point in giving a detailed case history of the sealing of a steam leak but in order to supplement the text, typical arrangements are shown in Figs. 48, 49 and 50.

A pipe for the supply of cyclohexane in a nylon plant developed a leak at a weld in a T-piece. The T-piece was part of an all welded line so could not be removed for repair. In situ welding could not be considered without a prolonged shut down whilst the plant was cleared of all solvents. The method adopted was to shut the line down and connect it at a terminal point to a steam line. A T-shaped clamp was fitted at the leak with an injection nozzle attached. Steam was passed through the line to provide heat. The compound was injected, allowed to cure, the steam was shut off and the line recommissioned.

9. DISCUSSION

The considerable experience which has been gained with the various repair techniques shows that they are easy to do and reliable in service even after a considerable time. In many cases the techniques show advantage over conventional methods such as welding. There is no restriction due to possible fire risks. Cast metals which may be difficult to repair by welding are not a problem. High local heat is not involved and, therefore, there is no risk of distortion.

The materials and techniques are quite versatile and because plant shutdown times can be reduced by the use of these techniques, considerable direct financial saving can be made.

The application of the material in what is often quite adverse conditions frequently suggests solutions to quite long term problems. Occasionally improvisation in emergency situations leads to improved procedure which compares very favourable with standard methods. For example, the knowhow which was developed for the remounting of machines quickly is now being adopted for the installation of new machines. Situations demanding emergency repairs are a source of worry to maintenance engineers but there are lessons to be learnt in these situations which can be of long term benefit.

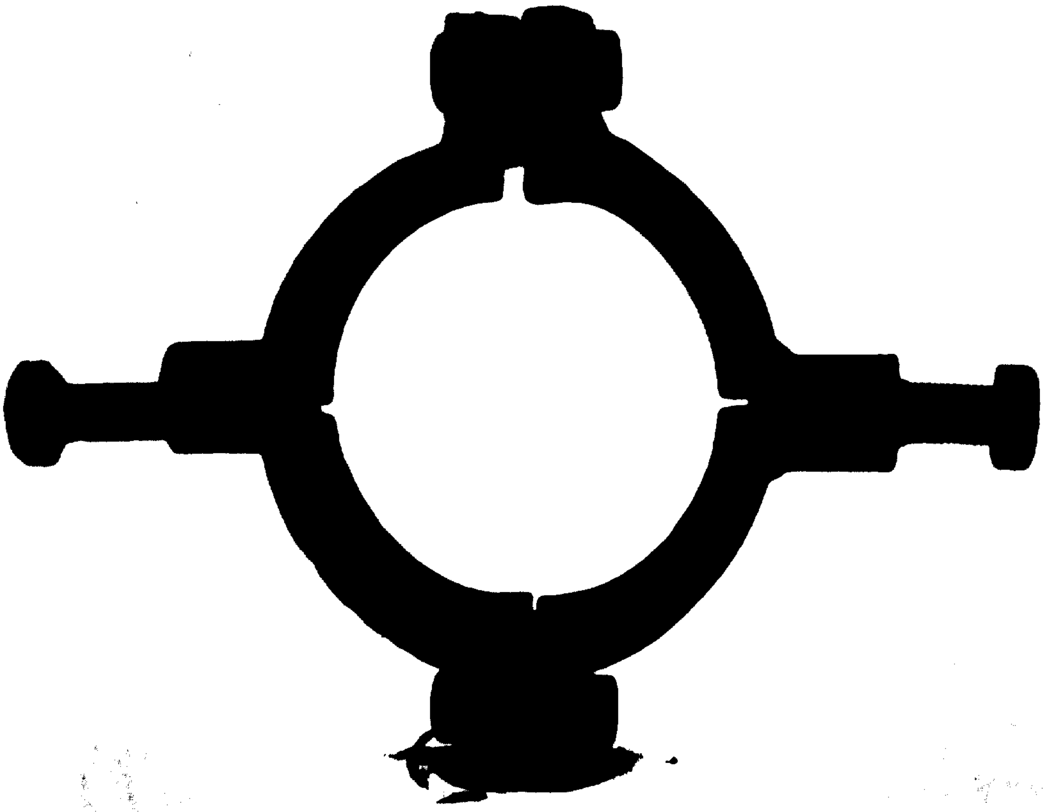

Fig. 46 Clamp for the Repair of a Flanged Joint

Fig. 49 Repair of a Leaking Joint in a Steam Line
General Arrangement

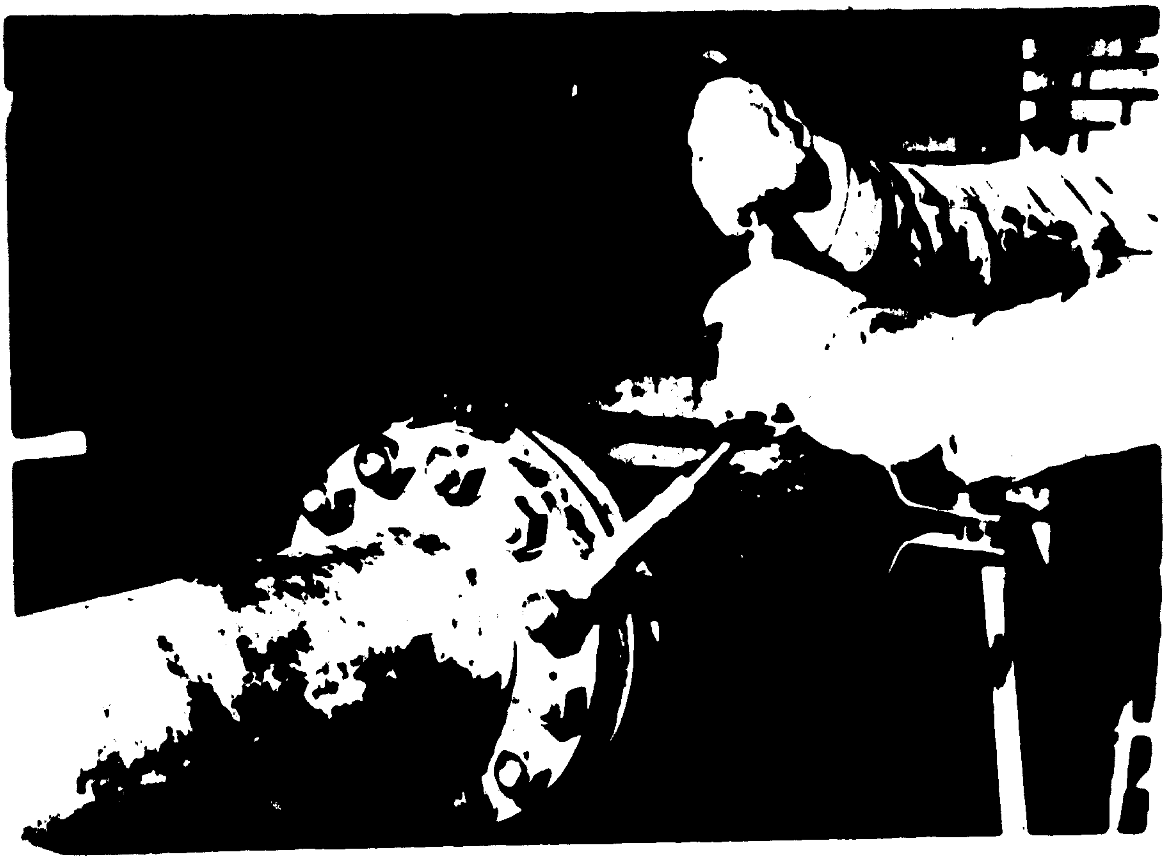

Fig. 50. Injecting Rubber through a Special Bolt for the Repair of a Steam Leak

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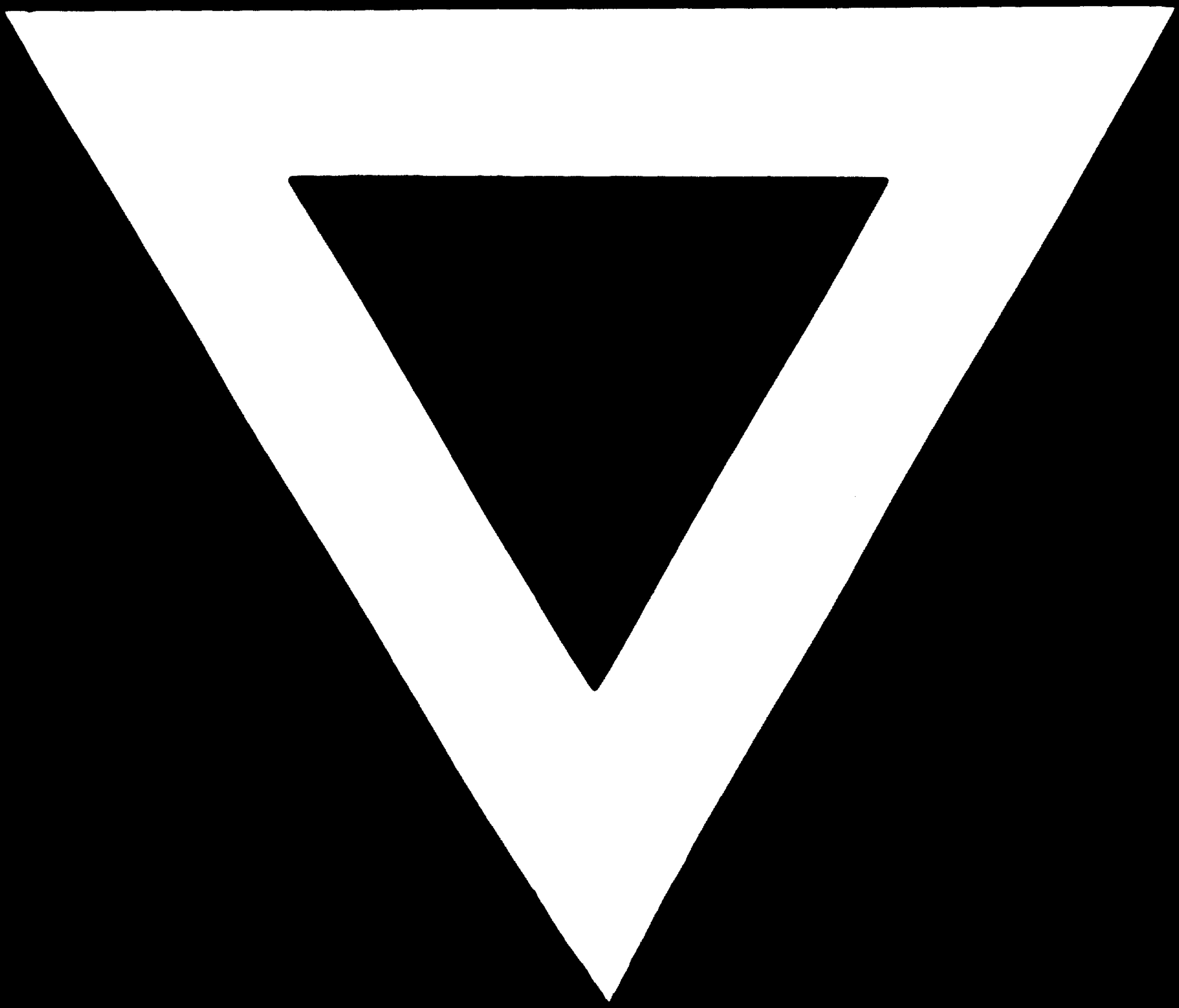

74.10.16