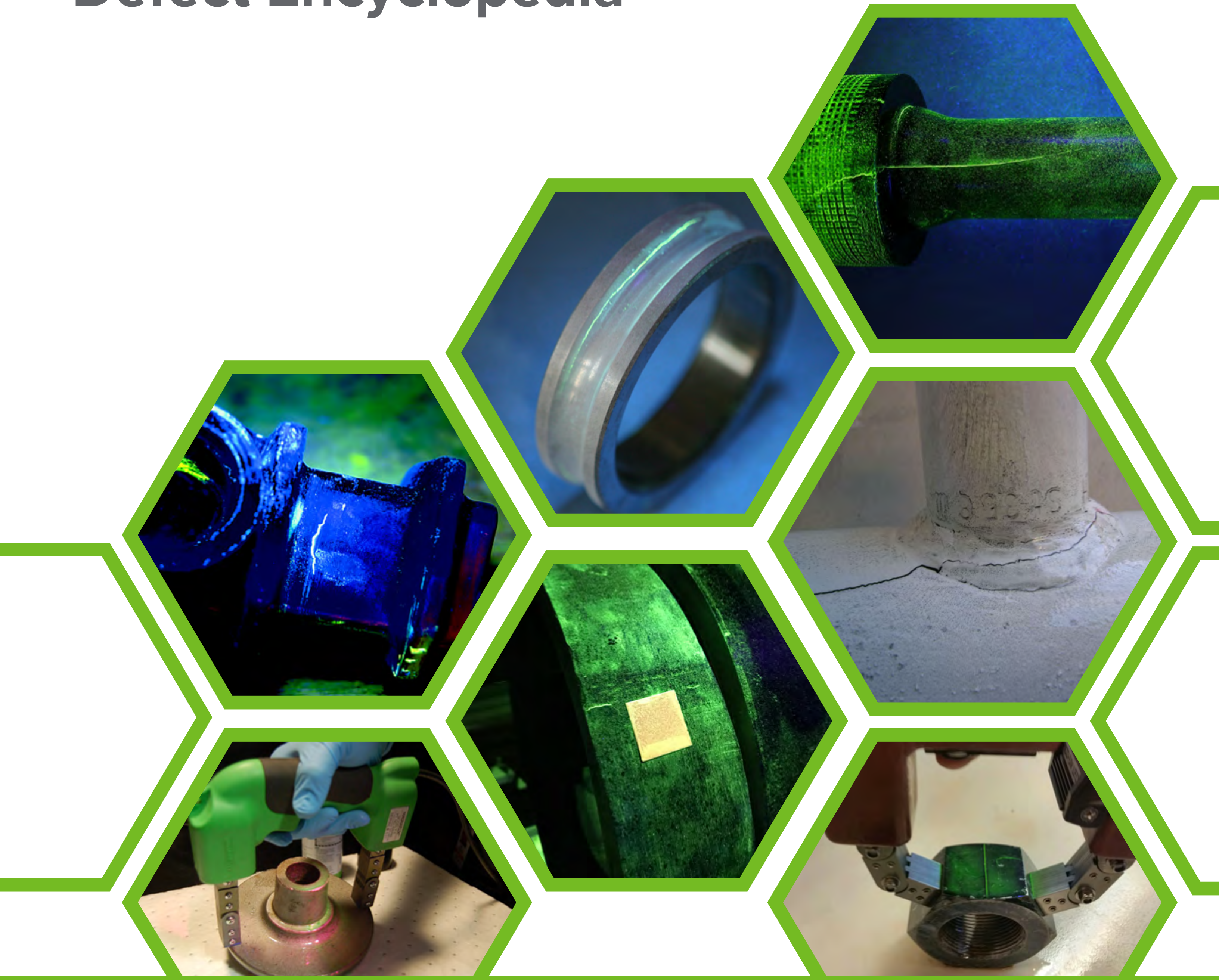
MAGNETIC PARTICLE

Magnetic Particle Defect Encyclopedia



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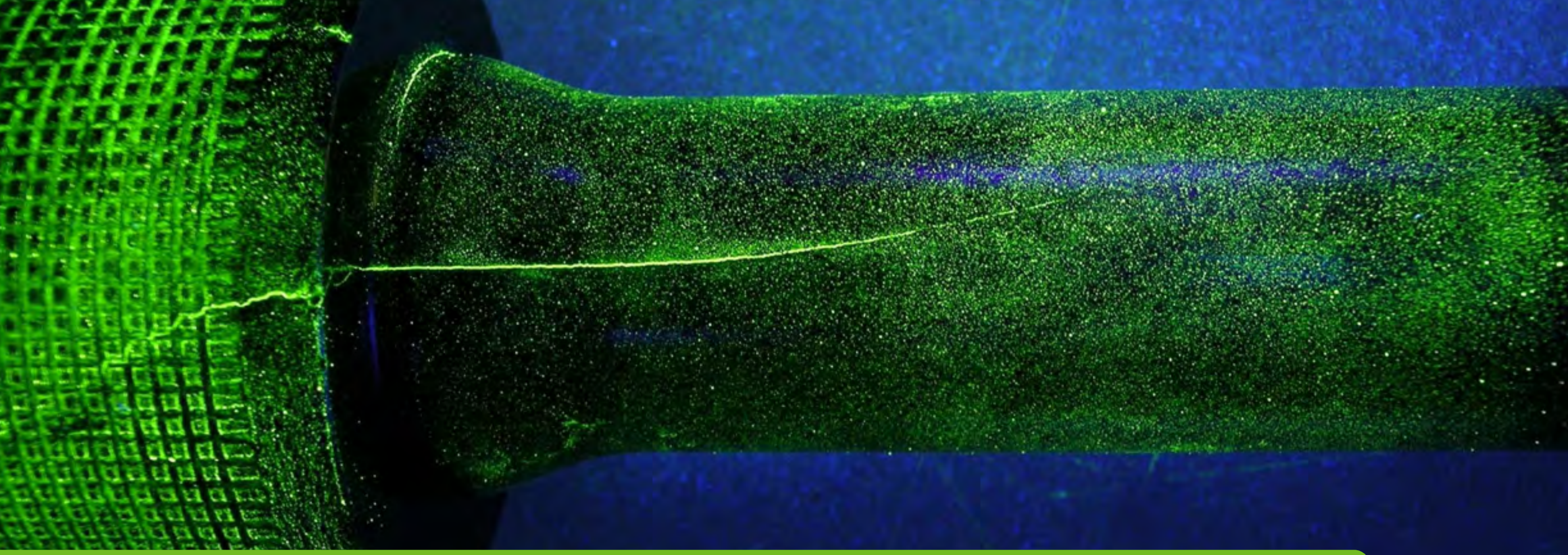


Magnetic Particle Defect Encyclopedia

During the quality assurance process, an inspector or QA Technician might use words like “flaw,” “discoloration,” or “blemish.” At first glance, one might assume that if a part had a “flaw” that it was defective and therefore unusable. The aforementioned descriptors are commonly used synonyms for the word “defect.” However, in the world of nondestructive testing, “defect” and its synonyms are not necessarily interchangeable.

For example, a part may have a blemish or a flaw in it and still not be ‘defective” in the sense that its usefulness for its intended purpose will be impaired. A spot or stain would have no effect on the service performance of a connecting rod of an automobile engine and would certainly not make it defective but on stainless steel exterior panel, such a spot might make the panel unusable and in turn render it defective.

So, how is a “defect” accurately defined in the language of nondestructive testing? Initially, everything found during MPI testing is classified as an “indication”. Then, based on what is causing the indication (part geometry, discontinuity, etc.) the indication is classified as relevant or non-relevant. Once an indication is determined to be relevant, then the acceptance criteria must be referenced in order to determine if the indication causes the part to be rejected.

Before we dive further into how a defect is appropriately categorized, we must consider also the state that occurs prior to a defect being defined. Here we find another common term: “discontinuity”.

“Discontinuity” addresses the condition, or an abnormal occurrence on a part, before it is determined whether it is a defect or not. The cause of magnetic particle indications is in all cases is a discontinuity- whether physical or magnetic. And if we exclude those discontinuities that are present by design and consider only those present in the metal by accident or the result of some manufacturing process, these may still not in all cases make the part defective in the sense that its service performance will be affected unfavorably. Therefore, we can conclude that a discontinuity is not necessarily a defect. It is a defect only when it will interfere with the performance of the part or material in its intended service. And a discontinuity which may make one part defective may be entirely harmless in another part designed for a different service. Further - as in the case of the panel - what would be only a blemish in most cases may become a defect in a product in which appearance is a major factor in acceptable service use.

There are a number of possible ways of classifying discontinuities that occur in ferromagnetic materials and parts. For many years it has been customary to classify discontinuities for the purpose of magnetic particle testing (as well as for other nondestructive testing methods) according to their source or origin in the various stages of production of the metal, its fabrication and its use.

Below are the commonly used categories for organizing magnetic particle discontinuities and what each of those categories entails:

Inherent

This group of discontinuities is present in metal as the result of its initial solidification from the molten state, before any of the operations to forge or roll it into useful sizes and shapes has begun.

Primary Processing

When steel ingots are worked down into usable sizes and shapes such as billets and forging blanks, some inherent defects may appear. But the rolling and forging processes may themselves introduce discontinuities which in many cases constitute defects. Primary processes are those which work the metal down, by either hot or cold deformation, into useful forms such as bars, rod and wire, and forged shapes. Casting is another process usually included in this group since, though it starts with molten metal, it results in a semi-finished product. Welding is similarly included for comparable reasons.

Secondary or Finishing Processing

In this group are those discontinuities associated with the various finishing operations, after the part has been rough-formed by rolling, forging, casting or welding. Discontinuities may be introduced by machining, heat treating, grinding and similar processes.

Service

In this group are those discontinuities associated with the various The fourth major classification of discontinuities comprises those which are formed or produced after all fabrication has been completed and the part has gone into service. The objective of magnetic particle testing to locate and eliminate discontinuities during fabrication, is to put the part into service free from defects. However, even when this is fully accomplished, failures in service still occur as a result of cracking caused by in use conditions.

Now that we have established what discontinuities are, we must consider our original question: what is a defect and how do we define it within the nondestructive testing world?

The word "defect" is correctly applied only to a condition which will interfere with the safe or satisfactory service of the particular part in question. An abnormality on a part at any stage is not automatically a defect, but rather, as explained above, it is a discontinuity which can be categorized based on the stage of production in which abnormality occurred. Once that discontinuity has been identified, then it can be determined if it will have an impact on a part's performance in which case it is then classified as a defect.

Inherent Discontinuities

While one might assume defects or abnormities occur during a part's manufacturing process, there are some discontinuities which occur before a part's creation even starts. These types of discontinuities are known as "inherent" and they are present in metal as the result of its initial solidification from the molten state, before any of the processes to forge or roll it into useful sizes and shapes has begun. Below are common inherent discontinuities you might encounter.

Pipe

As the molten steel which has been poured into the ingot mold cools, it solidifies first at the bottom and walls of the mold. Solidification progresses gradually upward and inward. The solidified metal occupies a somewhat smaller volume than the liquid, so that there is a progressive shrinkage of volume as solidification goes on. The last metal to solidify is at the top of the mold, but due to shrinkage there is not enough metal to fill the mold completely, and a depression or cavity is formed. This may extend quite deeply into the ingot. After the early breakdown of the ingot into a bloom, this shrink cavity is cut away or cropped. If this is not done completely before final rolling or forging into shape, the unsound metal will show up as voids called "pipe" in the finished product. Such internal discontinuities, or pipe, are obviously undesirable for most uses and constitute a true defect. Special devices ("hot tops") and special handling of the ingot during pouring and solidifying can, to a large degree, control the formation of these shrink cavities.

Blowholes

As the molten metal in the ingot mold solidifies, there is an evolution of various gases. These gas bubbles rise through the liquid and many escape. Many, however, are trapped as the metal freezes. Some, usually small, will appear near the surface of the ingot; and some, often large, will be deeper in the metal, especially near the top of the ingot. Many of these blowholes are clean on the interior and are welded shut again into sound metal during the first rolling or forging of the ingot; but some, near the surface, may have become oxidized and do not weld. These may appear as seams in the rolled product. Those deeper in the interior, if not welded shut in the rolling. may appear as laminations.

Segregation

Another action that takes place during the solidification of the molten metal is the tendency for certain elements in the metal to concentrate in the last-to-solidify liquid resulting in an uneven distribution of some of the chemical constituents of the steel as between the outside and center of the ingot. Various means have been developed to minimize this tendency, but if for any reason sever segregation does occur, the difference in permeability of the segregated areas may produce magnetic particle indications. Unless severe, such segregation is generally not deleterious.

Non-metallic Inclusions

All steel contains more or less matter of a non-metallic nature. The origin of such matter is chiefly the de-oxidizing materials added to the molten steel in the furnace, the ladle or the ingot mold. These additions are easily oxidizable metals such as aluminum, silicone, manganese and others. The oxides and sulfides of these additions constitute the bulk of the non-metallic inclusions.

When finely divided and uniformly distributed, such non-metallic matter does not usually injure the steel. However, it sometimes gathers into large clumps which, when rolled out, become long "stringers." These stringers in some cases are objectionable. When such a string occurs at the surface or just under the surface of a highly stressed part or bearing surface, it may lead to fatigue cracking.

In general, non-metallic inclusions in steel seldom constitute a real defect, though they are often indicated with magnetic particles. Non-metallic inclusions are sometimes added to steel intentionally. The addition of lead of sulfur to steels for the purpose of improving machinability is common practice. Such steel will show excessive amounts of non-metallic inclusions, which serve to break up the chips when the metal is turned or otherwise machined. Machine time is reduced, and tool life is lengthened. Such steels, if tested with magnetic particles, may show a alarming looking patterns, which have no significance as defects. The magnetic particle must be familiar with this type of steel.

Though serving a useful purpose in their proper field, these steels should never be used for critical or highly stressed parts or parts subject to fatigue in service.

Internal Fissures

Because of the stresses set up in the ingot as the result of shrinkage during cooling, internal ruptures may occur which may be quite large. Since no air normally reaches the surfaces of these internal bursts, they may be completely welded shut during rolling or other working and leave no discontinuity. If there is an opening from the fissure to the surface, however, air will enter and oxidize the surfaces. In such a case welding does not occur, and they will remain in the finished product as discontinuities.

Scabs

When liquid steel is first poured into the ingot mold there is considerable splashing or spattering up and against the cool walls of the mold. These splashes solidify at once and become oxidized. As the molten steel rises and the mold becomes filled, these splashes will be reabsorbed to a large extent into the metal. But in some cases, they will remain as scabs of oxidized metal adhering to the surface of the ingot. These may remain and appear on the surface of the rolled product. If they do not go deeply into the surface, they may not constitute a defect, since they may be removed on machining.

Ingot Cracks

Surface cracking of ingots occurs due to surface stresses generated during cooling of the ingot. They may be either longitudinal or transverse, or both types may occur together. As the ingot is worked into billets by rolling, these cracks form long seams. Inspection of quality-product billets for seams of this type with magnetic particles is now common practice in modern mills. This permits removal of the seams by flame scarfing, chipping or grinding without waste of good metal. If not removed before further rolling these deeper seams appear, greatly elongated, on finished bars and shapes, often making them unsuitable for many purposes.

Primary Processing Discontinuities

When steel ingots are worked down into usable sizes and shapes such as billets and forging blanks, some inherent discontinuities may appear. But the rolling and forging processes may themselves introduce discontinuities which in many cases constitute defects. Primary processes are those which work the metal down, by either heat or cold deformation, into useful forms such as bars, rod and wire, and forged shapes. Casting is another process usually included in this group since, though it starts with molten metal, it results in a semi-finished product. Welding is also included for similar reasons.

Seams

Seams in rolled bars or drawn wire are usually highly objectionable and often downgrade the product and make it unusable for first quality purposes. Severe seams may originate from ingot cracks, but by proper cleaning up (conditioning) of the billets by scarfing, grinding or chipping these' can be eliminated before final rolling. Conditioning is usually aided by the use of magnetic particle testing to indicate the length and severity of the seams. If properly conditioned at the billet stage, seams from this source need not appear in the final rolled product. But seams can be introduced by the rolling or drawing processes themselves. Laps can occur in the rolling of the ingot into billets as the result of over-filling of the rolls. This produces projecting fins, which on subsequent passes are rolled into the surface of the billet or bar. When severe, the billet often cannot be salvaged and is downgraded. Similarly, even when billets have been conditioned and are free of seams, are rolled into bars or rods, laps result from over-filled rolls can occur, producing long and often very deep seams in the finished product. In similar fashion, under-fills in the rolling process may, on subsequent passes, be squeezed to from a seam which often runs the full length of the bar at an acute angle. Seams derived from the folds produced by an under-filled pass are likely to be nearly normal to the surface of the bar. Seams or die marks may also be introduced in the drawing process due to defective dies. Such seams may or may not make the product defective. For some purposes, such as springs or bards for heavy upsetting, the most minute surface imperfections or discontinuities are cause for rejection. For others, when for example, machine operations are expected to remove the outer layers of metal, seams which are not too deep will be machined away.

Laminations

Laminations in rolled plate or strips are formed when blowholes or internal fissures are not welded tight during rolling but are enlarged and flattened into areas of horizontal discontinuities. Laminations may be detected by magnetic particle testing on the cut edges of plate but do not give indications on plate or strip surfaces, since these discontinuities are interal and lie in a plane parralal to the surface. Ultrasonic inspection techniques can be used to locate and define them.

Cupping

This is a condition created when, in drawing or extruding a bar or shape, the interior of the metal docs not flow as rapidly as the surface. Segregation in the center of the bar usually contributes to the occurrence. The result is a series of internal ruptures which are severe defects whenever they occur. They may be indicated with magnetic particles, but only if the ruptures are large and approach the surface of the bar. The cupping problem can be minimized by changing die angles.

Cooling Cracks

When alloy and tool steel bars are rolled and subsequently run out onto a bed or table for cooling, stresses may be set up due to U11evcn cooling which can be severe enough to crack the bars. Such cracks are generally longitudinal, but not necessarily straight. They may be quite long and usually vary in depth along their length. Magnetic particle indication varies in intensity, being heavier at points where the crack is deepest.

Flakes

Flakes are internal ruptures that may occur in steel as the result of too rapid cooling. It is believed that the release of dissolved hydrogen gas during the cooling process causes these ruptures. and that controlled slow cooling after forging or otherwise hot working the metal will reduce their occurrence. Flaking usually occurs in fairly heavy sections and certain alloys are more susceptible! than others. Since these ruptures are deep in the metal-usually half way and more from the surface, they will not be shown by magnetic particle testing on the original surface of the part.

Forging Bursts

When steel is worked at improper temperatures it is subject to cracking or rupturing. Too rapid or too severe a reduction of temperature in a section can also cause bursts or cracks. Such ruptures may be internal bursts, or they may be cracks on the surface. When on the surface, they are readily found by magnetic particle testing. If within the interior, they are usually not shown except when they have been exposed by machining.

Forging Laps

As the name implies, forging laps or folds are formed when, in the forging operation, improper handling of the blank in the die causes the metal to flow so as to form a lap which is later squeezed tight. Since it is on the surface and is oxidized, this lap does not weld shut. This type of discontinuity is sometimes difficult to locate, because it may be open at the surface and fairly shallow, and often may lie at only a very slight angle to the surface. Jn some unusual cases it also may be solidly filled with magnetic oxides.

Buring

Overheating of forgings, to the point of incipient fusion, results in a condition which renders the forging unusable in most cases and is referred to as burning. Actual oxidation is, however, not the real source of the damage, but rather the partial liquidation due to heat, of material at the grain boundaries. Burning is a serious defect but is not generally shown by magnetic particle testing.

Flash Line Tears

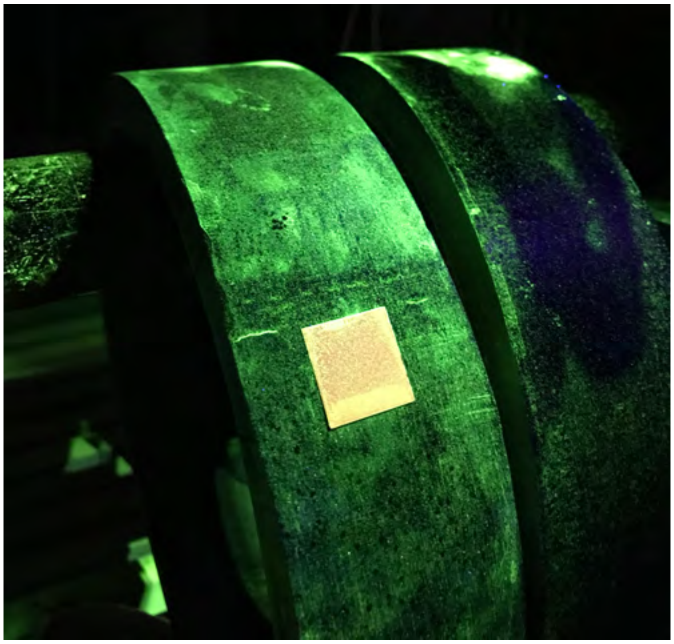
Cracks or tears along the flash line of forgings are usually caused by improper trimming of the flash. If shallow, they may “clean up” if machined, and do not make the part defective; or they may be too deep to clean up and in such cases the forging cannot be salvaged. Such cracks or tears can easily be found by magnetic particles.

Castings

Steel and iron castings are subject to a number of defects which magnetic particle testing can easily detect. Surface discontinuities are formed in castings due to stresses resulting from cooling and are often associated with changes in the cross section of the part. These may be hot tears or there may be shrinkage cracks which occur as the metal cools down. Sand from the mold, trapped by the hot metal, may form sand inclusions on or near the surface of castings. Gray iron castings may be quite brittle and are often cracked - usually at thin sections-during the “shake-out” or by rough handling during sorting.

Weldments

A number of kinds of discontinuities may be formed during welding of both thin and heavy sections. Some are at the surface am! some are in the interior of the metal. Some of the defects peculiar to weldments are lack of penetration, lack of fusion, undercutting, cracks in the weld metal, crater cracks, cracks in the heat affected zone, etc.



Secondary Processing and Finishing Discontinuities?

This group of discontinuities is associated with the various finishing operations, after the part has been rough formed by rolling, forging, casting or welding. Discontinuities may be introduced by machining, heat treating, grinding and similar processes. Secondary processing discontinuities differ from primary processing discontinuities in that these are discontinuities that occur during processes which result in a finished product rather than a part which requires additional processing.

Machining Tears

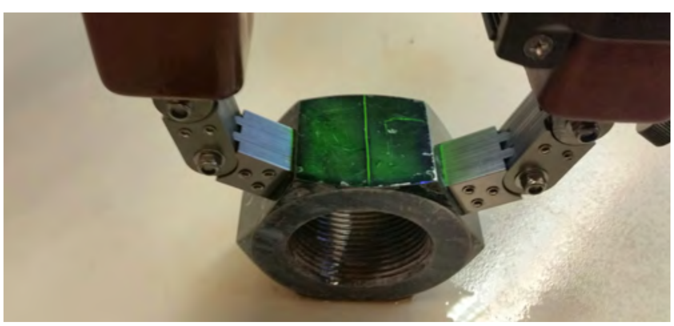
These are caused by dragging of the metal under the tool when it is not cutting cleanly. Soft and ductile low carbon steels are more susceptible to this kind of damage than are the harder, higher carbon or alloy types. Machining tears are surface discontinuities and are readily found with magnetic particles.

Heat Treating Cracks

When steels are heated and quenched to harden them, or are otherwise heat treated to produce desired properties for strength or wear, cracking may occur if the operation is not correctly suited to the material and the shape of the part. Most common are quench cracks, caused when parts are heated to high temperatures and then suddenly cooled by immersing them in some cool medium, which may be water, oil or even air. Such cracks often occur at locations where the part changes section from light to heavy - or at fillets or notches in the part. The edges of keyways and the roots of splines or threads are likely spots to watch for quenching cracks. Cracks may also result from too rapid heating of the part, which may cause uneven expansion at changes of cross-section, or at corners where heat is absorbed from three sides-more rapidly than in the body of the piece. Corner cracking may also occur during quenching because of more rapid heat loss at such locations. Heat treating cycles can be designed to minimize or eliminate such cracking, but for critical parts, testing with magnetic particles is a safety measure usually applied, since such cracks are serious and their detection presents no difficulty.

Straightening Cracks

The process of heat treating often causes some warping of the part due to slight unevenness in the cooling during quenching. A hardened shaft, for example, may come from the heat treat operation not quite straight. In many cases these can be straightened in a press, bcracks the amount of bend required is too great, or if the shaft is very hard, cacks may be formed. These, again, are very readily found with magnetic particles.



Grinding Cracks

Surface cracking of hardened parts as the result of improper grinding is frequently a source of trouble. Grinding cracks are essentially thermal cracks and are related to quenching cracks in more ways than one. They are caused by stresses set up by local heating under the grinding wheel. They are in nearly all cases avoidable if proper wheels, proper cuts and proper coolants are used, and if wheels are properly dressed when required. But since proper grinding requires constant attention and care which is not always provided in practice, these defects do occur. Since they are sharp surface cracks they are easily located with magnetic particles, even if shallow, and locating them is usually of vital importance. Salvage of the cracked part is seldom possible since grinding is usually a final precision finishing operation. The best use of magnetic particle testing in this case is to conduct sampling tests to monitor the grinding operation and thereby control it to avoid the formation of grinding cracks. Hardened surfaces often retain internal stresses from the quenching operation which are not severe enough to cause cracking at the time of quenching. During grinding, however, the relatively small increment of stress set up by local heating under the grinding wheel may cause rupture when added to the residual stress already present. Such surfaces usually crack severely and extensively.

Etching and Pickling Cracks

Hardened surfaces which contain residual stresses may be cracked if they are pickled or etched in acid. Attack by the acid of the surface' fibers of the material gives the internal stress a chance to be relieved by the formation of a crack. Before this action was fully understood, the heat treatment of the part was often blamed for the cracking, when such cracking actually occurred during acid cleaning for plating or other purposes. The heat treat operations did, however, deserve some of the blame, by leaving the part with internal residual stress locked up.

Plating Cracks

When hardened surfaces are to be electroplated, care must be taken to ensure that pickling (or other cleaning operations preparatory to plating) does not produce cracks. Sometimes cracks are formed during the plating operation itself. Residual stresses leading to etching or plating cracks may also be the result of cold work. Spiral springs, cold work, then pickled for plating or hot galvanizing, have also shown such cracks. The hot galvanizing process itself may also produce cracks in surfaces containing residual stresses. Penetration of the hot zinc between the grain boundaries during the hot dip process provides points for relief of such stresses by the formation of cracks. Copper penetration during brazing may result -in similar cracking if the parts contain residual stresses. Mollen alloys from the bearing of a railroad axle journal during a “hot box” will penetrate the surface of the heated journal and provide the starting point for a fatigue crack and axle failure.

In-Service Discontinuities

One of the most common classifications of discontinuities, service discontinuities comprise discontinuities which are formed or produced after all fabrication has been completed and the part has gone into service. The objective of magnetic particle testing to locate and eliminate discontinuities during fabrication to put the part into service free from defects. However, even when this is fully accomplished, failures in service still occur as a result of service conditions.

Fatigue Cracks

As a source of discontinuities, the phenomenon of fatigue is a prolific one. Metals which are subjected to alternating or fluctuating stresses above a certain critical level (the fatigue strength) will eventually dew lop cracks, and finally fracture. Fatigue cracks, even very shallow ones, can readily be found with magnetic particles, and the part often can be salvaged.

Corrosion

Parts which are under tension stress in service and are at the same time exposed to corrosion from whatever cause may develop cracking at the surface, referred to as stress corrosion cracking. Such cracks, under continuing corrosion and stress (whether reversing. or fluctuating or not) will progress through the section until failure occurs. When corrosion is added to fatigue-producing service conditions, this level of service failure is called corrosion fatigue.

Overstressing

Parts of an assembly in service that are stressed beyond the level for which they were designed are very likely to crack or break. Such overstressing may occur as the result of an accident; or a part may become overloaded due to some unusual or emergency condition not anticipated by the designer; or a part may be loaded beyond Its strength because of the failure of some related member of the structure. After complete failure has occurred magnetic particle testing obviously has no application as regards the fractured part. But other parts of the assembly which may appear undamaged may have been overstressed during the accident or overloading from other causes. Examination by magnetic particle testing is usually carried out in such cases to determine whether any cracks have actually been formed. With this precaution salvage of good parts after an assembly failure is often possible.

Ready to discuss the discontinuities in your manufacturing process and how to find them? Connect with our expert team by visiting **www.magnaflux.com** or contact Magnaflux customer service at **support@magnaflux.com** or +1 847-657-5300.