KnightHawk Technical Overview: Metallurgical Failures
Somebody Messed Up: Material Defects and Operator Error

Overview: While all failures can be related to a human error on some level (e.g. through faulty design or poor process control), there are some failures that are more directly traceable to a single error. This error can be in the manufacturing of the failed component (e.g. a large welding defect or counterfeit materials) or in the installation of the failed component (e.g. misaligned bearings). Material defects account for approximately 11% of the failures studied by KnightHawk Materials Lab (KML), and operator error accounts for approximately 6% of the failures we study. Thus, human error, be it accidental or potentially malicious, is directly responsible for approximately 1 out of every 6 metallurgical failures in the oil, gas, and petrochemical industries analyzed by KML.

Material Defects: When we talk about material defects, what we are addressing are materials that have a fundamental flaw that limits or removes the materials ability to perform as intended. These defects come in a variety of forms, of which the most critical are discussed.

Weld Defects: Welding is a critical process for joining materials together that is used heavily throughout the world, and is used especially heavily in the construction of large steel and stainless-steel equipment, such as that used in the oil, gas, and petrochemical industries. As such, KML sees a large number of welds. In many, or even most, cases, the weld does not play a significant role in the failure of a part. However, in some cases, the weld does lead to part failure. Here it is important for us to differentiate between normal welds and defective welds. The process of welding heats the material to extreme temperatures and imparts stresses on the material, as well as creating geometric stress risers on the material surface. These issues can then be mitigated (as is done through post weld heat treatment or machining, when required), but properly performed welds do not represent a material defect as the part should be designed to account for the stress of welding. However, there are a number of issues that can arise with welding that cause a problem beyond those expected from normal welding operations. These include the formation of weld gaps (locations where the weld bead did not fully bond to the material, resulting in areas with voids or scales that form stress risers in the material), overly large or sensitized heat affected zones or micro-fissures in the weld (both often caused by two short of a weld interpass time), and improperly mitigated welds (such as when a post-weld heat treatment is needed but is not performed). Regardless of the cause of the welding defect, the most common location for weld cracks to occur is at the interface between the weld metal and the heat affected zone, as shown in Figure 1.

Poor Heat Treatment: Improper heat treatment of materials can cause significant deficiencies in the mechanical properties of those materials. In high strength steels temper embrittlement and tempered martensite embrittlement are known to occur when steels are heat treated or slow cooled through various temperature ranges. These forms of embrittlement do not have a large effect on the materials hardness or tensile properties, but they do significantly impact the materials toughness, making the material susceptible to sudden brittle failure under conditions in which that failure would not normally be expected. Stainless steels, especially austenitic stainless, are susceptible to sensitization (the precipitation of chromium carbide on the grain boundaries) when heated within certain temperature ranges, making the material susceptible to intergranular corrosive attack in the adjacent chromium depleted regions. Other problems that can arise from poor heat treatment are out of specification mechanical properties, insufficient corrosion resistance, and the formation of microstructural abnormalities. Figure 1 shows a part that underwent sensitization as a result of welding. Figure 2 shows a cross section of a fracture in a part that underwent martensite embrittlement, showing segregation of P to the fracture surfaces (seen by the P concentration spikes corresponding with the edges of the fracture).

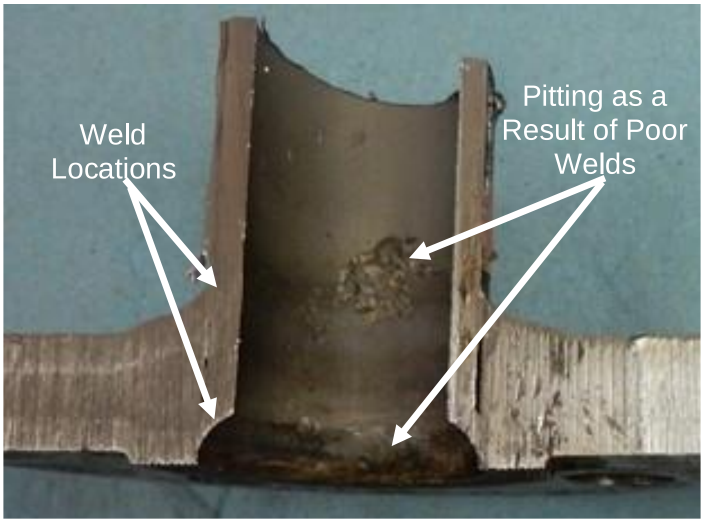

Figure 1: Welding defects (too short of an interpass time) resulting in stainless steel sensitization enabling intergranular corrosion and through thickness pitting of a pipe welded to a flange.

Counterfeit Materials: Occasionally, either through error or malicious intent, the material that a part is supposed to be made out of is not the material that the part is actually manufactured out of. This can be through poor chemistry control or, in the most egregious of cases, intentional misrepresentation of a, usually, less expensive material for a more expensive one. Regardless of the cause, the result of having out of specification materials in service is usually a failure of the part.

KnightHawk Technical Overview: Metallurgical Failures
Somebody Messed Up: Material Defects and Operator Error

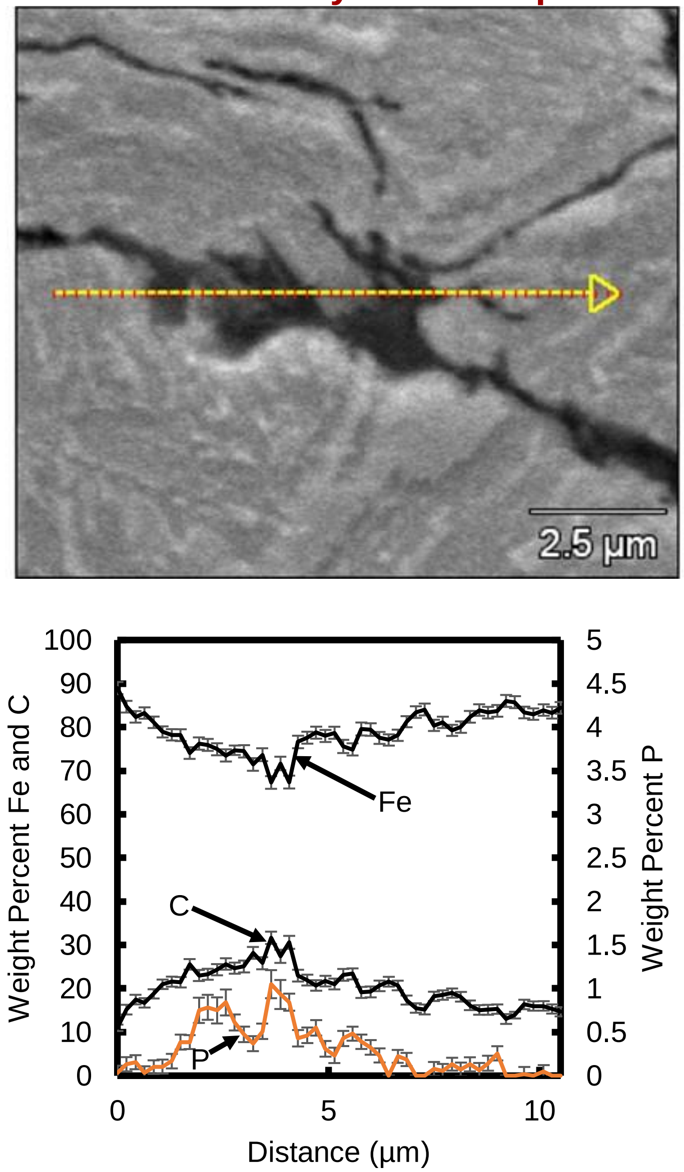

Figure 2: Martensite embrittlement resulting in P segregation to carbide interfaces, resulting in the fracture of the embrittled material.

<u>Operator Error:</u> Operator error is the term that KML uses to refer to materials that fail due to end user actions outside of normal operation. For example, improperly performed maintenance or startup-shutdown procedures resulting in material failures is considered operator error, whereas poor water chemistry control resulting in corrosion is not.

<u>Improper Installation:</u> Improper installation is a somewhat self-explanatory title with an equally obvious path to failure – if a part is not installed properly, the chances that it will fail prematurely greatly increase. This failure mode is most often seen in moving parts (with bearings being the most common, although other parts are subject to this as well, such as swivel joints in high pressure fracking lines), where slight misalignment of the part can lead to severe changes in the loading that ultimately result in premature failure. Figure 3 shows the remains of a bearing that experienced contamination upon installation that ultimately led to a premature failure.

Figure 3: A bearing that failed catastrophically as a result of contamination during installation.

<u>Improper Operation:</u> Improper operation does not cover operational design issues such as too high of a load or process control. Instead, this covers things such as loss of lubrication, introduction of foreign material (often grit), or other related conditions. While these failures do not necessarily occur often, when they do the results can often be catastrophic as they can cause severe friction, often leading to seizing of the equipment at a minimum or fire at the most catastrophic level.

<u>Conclusions:</u> Human error is an undeniable cause of failure and, until humans become perfect in everything they do, it will continue to cause failures in industry. Of the failures observed by KML, the majority have to do with material defects (the most common one being weld defects), but there is also an undeniable role of operator error. The majority of these failures could likely be prevented through more comprehensive training on manufacturing and maintenance procedures. Of course, also included in this category are counterfeit materials, which are unique in that they sometimes are not an accident but are instead a malicious attempt to pass a lower grade of material off as a higher grade as a cost saving measure. Stay tuned for the next installment in our metallurgical failures series, "Everything Has a Breaking Point: Overload Failures."

Written By: Dr. Michael Hoerner, Lab Director