What is a brittle fracture

What is Brittle Fracture? The term ductile and brittle is used to distinguish failures of materials characteristics by high and low toughness respectively. Brittle Fracture is the sudden & very fast cracking of material or equipment under stress. A brittle fracture occurs without any plastic deformation (No thinning or necking) or little deformation only by direct separation along crystallographic planes due to a simple breaking of atomic bonds. In brittle fracture, materials show no warning before failure, hence brittle fracture can be catastrophic in nature. After failure material broke into many pieces with little to no deformation in shape. The surface appearance of brittle fracture is relatively smooth and is often shiny in appearance. Although not all brittle fracture is perfectly smooth some brittle fracture demonstrates Chevron markings appear in the fracture area. In a Charpy Impact test, brittle metal will absorb a small amount of energy when impact tested, while a tough ductile metal absorbs a large amount of energy. Pure brittle fracture is called cleavage fracture. Mechanism of Brittle Fracture Brittle fracture is usually due to low temperatures in ferritic & martensitic materials whereas austenitic materials exhibit ductile behavior even at low temperatures. If the material temperature or let's assume Steel is at or below its brittle-to-ductile transition temperature, then it will be highly susceptible to brittle fracture. This situation can be aggregated by the presence of defects (e.g. notch or crack) and high stress on this defect (either applied or residual), -which will most likely result in brittle fracture. Factors affecting Brittle Fracture in a material Below are the factors that can increase the susceptibility to brittle fracture: Metallurgical Degradation Materials properties degradation (Temper embrittlement, sigma phase embrittlement, graphitization, and 885°F or 475°C embrittlement) resulted due to elevated temperature applications. These failure mechanisms if present will aid in material failure by brittle fracture. Material Cleanliness and Grain Structure In the case of steel, material toughness can be decreased due to large grain sizes and steel contaminants, thus making the material more brittle. The addition of alloying elements which can affect its microstructural properties are can also make the material brittle. For metals, the microstructure grain size is a strong determinant of notch toughness. The grain size has a profound effect on the yield stress and strain hardening rate and it is, hence, logical to expect grain size to influence fracture toughness. Microstructure with fine grains possesses high mechanical properties while coarse grain microstructure is prone to brittle fracture. Example- Cast iron having coarse grain is highly brittle while a forging with fine grain offers high mechanical properties. High Material Thickness Both geometry of cross-section and its size can influence the nominal strength of a material. Actually most of the materials show a marked size effect, for example, large sections are more prone to brittle fracture. The determination in the strength of thick sections has been attributed to the increased amount of impurities, flaws, and discontinuities present in thick sections. Thick materials are more prone to brittle failure due to the high tri-axial force working on them. Thick plate thickness has high restraint and can absorb more residual stresses without showing any significant deformation. High residual stresses The heating and cooling cycles of welding result in the development of residual stresses. The stress level in a welding joint could be large enough to reach the yield point of the material and may lead to brittle fracture in the presence of any crack. The combination of welding residual stresses and material strain aging is considered to be a known cause of brittle fracture. Brittle fracture is more likely in the presence of high residual stresses or if the structure is highly loaded, particularly under a high strain rate (impact loading). Stress concentrations (from weld toes, change of section, notches) and weld defects (such as cracks or lack-of-fusion) can have a major effect on the likelihood of brittle fracture. Susceptibility of brittle fracture could be induced by a triaxial stress state like imposition of a high strain rate. Low temperature The ductile to brittle transition in steels at low-temperature influences whether a failure will be ductile or brittle. At low temperatures, the material has lower fracture toughness and is more prone to brittle fracture. Low toughness is more likely in materials with a crystalline structure which is body-centered cubic (bcc) ferritic steels because they show the toughness transition, compared with those with face-centered cubic (FCC) crystal structures, such as austenitic stainless steel or aluminum which do not show a marked transition between ductile and brittle behavior. Low toughness can result from the steel's microstructure as a fine grain size has high toughness whereas martensite or coarse grain HAZ have low toughness. Material thickness also has an effect on the fracture toughness with thick material having lower effective toughness than thinner plate made from the same material. Appearance of Brittle Fracture Brittle fracture can appear intergranular (between grains) and transgranular (within grains). The characteristic of brittle fracture is that there is little or no plastic deformation (necking or thinning) before failure. The fracture surface can reveal chevron marks or river lines pointing back to the fracture starting point as stated earlier in this post. In a brittle impact fracture, the fracture face is rough but not torn and will sometimes have a crystalline appearance (particularly under high strain rate loading, for example in a Charpy specimen). Types of Brittle fracture There are two main types of brittle fractures in materials: Transgranular andIntergranular. In transgranular fractures (within grains) as shown in the below picture- the fracture occurs through the material grains. The path of fracture changes from one grain to another because it follows the least resistance during fracture. Intergranular brittle fracture (Between grains)- appears along the grain boundaries as shown in the above picture. This type of fracture occurs due to weak & brittle grain boundaries. This usually occurs when there has been a process to weaken the grain boundaries. Intergranular or intercrystalline fracture involves pulling apart the individual crystals from their adjacent crystals. Such fractures are caused by the presence of impurities at the grain boundaries. Prevention of brittle fracture shall be taken into consideration during the component design stage. The operating temperature of the material must be at or above its brittle-to-ductile transition temperature during service and testing. Anticipated repairs of brittle materials must be considered and preventive measures shall be put in place before commencing the repairs. brittle fracture vs ductile fracture Brittle fracture of material refers to the type of failure mechanism where material shows little or no deformation and it's a sudden failure without any warning. Breaking of rock, glass, cast iron is an example of brittle fractures as they break without any deformation. A ductile fracture means fracture of material with large plastic deformation (Thinning or necking) before fracture. Fracture of mild steel and other ductile metals such as copper, nickel, rubber, and plastics is an example of ductile fracture. Recent Posts link to 5 best welder pants (FRC) for men and women link to What are the difference Between NR-211-Mp and E71T-1? Welcome to material Welding. Your trusted & single source for Welding, NDT & Corrosion topics, Online Calculators & Learning Videos. Visit our YouTube Channel MATERIAL WELDING, Subscribe and support our work. Read More 5 best welder pants (FRC) for men and women What are the difference Between NR-211-Mp and E71T-1? E6010 (E4310) vs E6011 (E4310)& differences between E6010 & E6011 rod What is CJP, PJP weld meaning, symbol, differences and examples? E8010, E8010-P1 (E5510-P1) welding rod, MTC, meaning, specification and chemical-mechanical properties What is the difference between ER70S-2 (ER49S-2) and ER70S-3 (ER49S-3)? What is the difference between ER70S-6 (ER49S-6) and ER70S-3 (ER49S-3)? E7018-1 or E4918-1-H4 electrode specification, meaning, chemical & mechanical properties with MTC ER70S-6 welding wire MTC, specification, chemical-mechanical properties Stick (SMAW) and TIG/ MIG Welding procedure for Inconel 625 A full appreciation of the mechanisms of fracture encountered in steels used to fabricate structures such as ships, bridges, pipelines or pressure vessels covers behaviour over a range of size-scales. The structures themselves are often extremely large: super-tankers and 'bulkers' over 200 m in length; bridge spans over 1500 m; the Kazakhstan–China pipeline, over 2000 km. Large modern structures are almost invariably fabricated by welding, so that the properties of the weld metal and the 'heat-affected zone' (HAZ) in the 'parent' metal adjacent to the weld interface need to be included in any assessment of the structure's integrity when subjected to service duty. The duty depends on application, but falls into one of two categories: that within the 'design intent' and that associated with (postulated) 'accident' events. Both must be addressed in safety justifications.The 'design intent' deals with 'normal' service duty. A bridge has its own deadweight, must bear traffic loads and is subjected to wind and wave loadings. Similar loadings are experienced by a tanker or a bulker carrying liquids (such as oil) or solids (such as minerals or grain) across the oceans; by an offshore drilling rig and by an offshore wind turbine (with added effects of whirling blades, to which the structure must provide reaction forces). A pipeline or pressure vessel has to contain the pressure of the medium that it contains. In addition, thermal stresses may be generated: either from simple day/night/day temperature changes or from excursions to and from high temperature in the operation of pressure vessels in chemical plant or in power generation plant. All these factors are included in the initial design. In broad terms, the design intent is for the structure to exhibit an overall elastic response to the stresses imposed by service duty. This is achieved by limiting the operating stresses to a fraction of the steel's yield strength, through a 'safety factor' specified in a design code. For pressure vessels, the safety factor is 2, i.e. the vessel is designed with dimensions such that the nominal stress associated with 'normal' service duty is limited to 50% of the yield strength. It should be recognized that a large amount of detailed calculation, involving both static and dynamic loading, is involved at this 'macro'-level.The second set of macroscale threats to structural integrity arises from accidental overloads, beyond those associated with the design intent. One cause of this is unforeseen natural forces, as demonstrated by the combination of tsunami and earthquakes at the Fukushimanuclear power plant in 2011, or by the Titanic's collision with an iceberg in 1912. Excessive overloads (not allowed for in the design calculations for the completed structure) may also be encountered during the construction phase. Examples are given by plastic collapse failures of a number of 'box-girder' bridges in the 1970s. Here, the buckling mechanisms for the hollow trapezoidal cross-sections of the 'boxes' in bending were not fully understood and excessive bending loads were applied during erection. Similar overload buckling failures can occur as a result of the incautious loading of cargo into bulkers. These carry solid material, and it is necessary for machinery (such as cranes and diggers) to be able to access the cargo in an unimpeded manner. A consequence is that there is minimal 'cross-bracing' in the holds and the bulker again assumes the form of a hollow box. If the loading of cargo is not sequenced in a designed manner, large bending moments can be generated and buckling collapse occurs. A spectacular example is that of 'Euro-bulker X' in 2000 at Levkandi, Greece. Guidance is now available to prevent such collapse [1], but ships may also fail by buckling collapse as a result of running aground, e.g. the 'Amoco Cadiz'. Such 'operational' failures do not fall within the scope of this paper, which is devoted to fractures that may occur under 'normal' service loadings, when the overall nominal stress is designed to be a fraction of the yield strength.Any such fracture necessitates the presence of a stress-concentrator in the structure, to enable localized yielding to occur and operate fracture mechanisms, when the nominal applied, stress is still a fraction of the yield strength. Such stress-concentrating features include changes in cross section (e.g. associated with fillets or stiffening plates), through-section penetrations or crack-like defects created during processing and fabrication. From a macroscopic engineering perspective, any fracture that occurs below the design stress is a (macroscopically) 'brittle' or 'fast' fracture and has to be addressed in an appropriate manner, but, at low temperatures, structural steels exhibit microscopically 'brittle' behaviour, as described below.There are many examples of brittle fractures in service. The most cited examples are those of welded Liberty ships and tankers, constructed during World War II. Between 1942 and 1952, 233 welded ships suffered one or more brittle fractures of severity such that the vessels were left in a dangerous condition; 19 broke in two or were completely abandoned; another 1200 experienced brittle cracks up to 3 m in length. Seventeen bridge failures occurred in Belgium between 1938 and 1950. The King's Bridge in Melbourne, Australia suffered a brittle fracture in 1962. Brittle failures in ships continue: three such are the World Concord in 1954, MV Kurdistan in 1979 [2] and the Selendang Ayu in 2004. Brittle fractures have also occurred in boilers and pressure vessels, even in the 'proof test' when 20% over-pressure is applied before the vessel enters service. One example was a boiler shell at Sizewell in 1963: another was that in 1965 of a vessel destined for use in ammonia conversion (figure 1). Figure 1. Brittle fracture of a steel pressure vessel during proof test. (The vessel walls were 149 mm thick, and a 2-tonne fragment was thrown 46 m). Courtesy TWI.Download figureOpen in new tabDownload PowerPointThe endpoint of a structural integrity assessment is the assurance that a structure will not fail under anticipated service duty, with a safety case that includes a set of postulated overload scenarios. As noted above, the structures of concern are very large, often 'one-off' for a specific application, and fabricated from a large number of individual components. It is not therefore possible to test full-size structures to failure, as is done, for example, for automotive engines. In some cases, specific tests may be made on 'features' or 'type tests' (e.g. fatigue tests on samples of the fabricated 'nodes' employed in offshore structures), but this is not always done, and many structures are constructed on the basis of design codes, measures of the material's suitability for service as inferred from specimen testing, and non-destructive inspection (NDI), to ensure that no defects of concern are present in the structure before it enters service. Periodic NDI is employed to guard against defect growth by any 'subcritical' crack growth mechanism (such as fatigue or environmentally assisted crack growth) during operation. In marine applications, loss of section thickness by salt-water corrosion needs also to be monitored. This paper concentrates on three size-scales, although one of these embeds a fourth: —   Fracture at the 'test-piece' scale, in both notched-bars and fracture toughness test-pieces and the use of data from such tests to make large-scale structural integrity assessments.—   Fracture at the 'microstructural' scale, relating values of local fracture stress or fracture toughness in test-pieces to the sizes and distributions of microstructural features. This leads to a treatment of how the microstructural understanding helps to address events at the 'meso'-scale in 'heterogeneous' or 'mixed' microstructures.—   Fracture at the 'nano' or 'atomistic' scale, considering how fracture might occur at the tip of an atomically sharp crack.In recognition of the fact that a stress-concentrator is necessary for (engineering-scale) brittle fracture to occur, measurement of the resistance to fracture of structural steels employs notched or pre-cracked test-pieces. Up to some 40 years ago, material quality was assessed, using notched-bar impact testing. A common example is the Charpy test, which subjects a bar of 10×10 mm cross section, containing a 45° V-notch of depth 2 mm and root radius 0.25 mm, to impact loading in a simple pendulum machine. The energy absorbed in fracture is measured as a function of test temperature, and is observed to undergo a transition from high-energy 'ductile' fracture at high temperature to low-energy 'brittle' fracture at low temperature. Ductile fracture involves the formation and coalescence of microvoids, centred on inclusions and other second-phase particles. A full treatment of these mechanisms would lengthen this paper unduly: details can be found in reference [3]. Two forms of brittle fracture may be observed: one is transgranular cleavage across {001} crystallographic planes (typically observed in normalized or annealed mild steels); the other is intergranular fracture along (ferrite grain-boundaries coincident with) prior-austenite grain-boundaries (observed in quenched-and-tempered alloy steels, resulting from the segregation of trace impurity elements such as P, Sn or Sb to such boundaries): see reference [4] in the theme issue.The main problem with notched impact tests is that the output information that they offer: energy absorption, transition temperature or fracture appearance cannot be used directly to calculate the failure stresses associated with defects in structures. These issues are discussed in more depth in reference [5]. Note, however, that notched impact values are still included in many steel quality specifications and, in the nuclear industry, due both to space limitations and to the dates at which the programmes were begun, many of the surveillance specimens used to monitor the effects of neutron irradiation on fracture properties are notched-bar impact test-pieces.Quantification of the applied stresses required to produce an engineering-scale 'brittle' or 'fast' fracture relies on the principles of fracture mechanics (see references [6,7] for more detailed treatment). The test-pieces contain sharp cracks (grown in by fatigue) and are loaded in tension (CTS) or bending at modest strain rate. The stress distribution over a short distance, r, ahead of an edge crack of length a, or a central crack of length 2a, lying normal to a uniform applied stress σ is given by 2.1 where K is the strength of the crack tip field: the crack tip stress intensity factor. For a central crack of length 2a normal to a uniform tensile stress σapp, K is given by 2.2 It assumes other forms for finite bodies or for non-uniform stresses, but the square-root dependency on crack length dominates. For standard test-piece geometries, K is directly proportional to stress and is related to test-piece dimensions, a (crack length) and W (test-piece width) through tabulated 'compliance functions', Y : K=σappY (a/W). The strain energy release 'rate' (dU/da=G) can be derived by a virtual work argument involving the crack tip stress and displacement fields—see [6–8]—to give, for the central crack under uniform stress, the identity 2.3 where E′ is Young's modulus, E, in plane stress, or E/(1−ν2) in plane strain; ν is Poisson's ratio. This result is seen to be identical to the usually recognized Griffith expression if the critical value of dU/da=G is equated to 2γ (where γ is the surface energy) and σapp is written as σapp(F) (the macroscopically applied fracture stress).Steels used in engineering structures are not ideal brittle solids, and the application of stress to a cracked body initially produces some local plasticity at the crack tip (before the crack propagates). Nevertheless, if the extent of such plasticity is small compared with the extent of the K-dominated field, it is possible to decouple the energy release rate, G, term from the work involved in propagating the crack, which is traditionally written as 2γ+γp, where γp is held to represent the 'plastic work of fracture'. Note, however, that most of the plastic work in a fracture toughness test precedes crack propagation (setting up a local stress state ahead of the pre-crack that facilitates the propagation of microcracks formed in brittle, second-phase particles: see below). More generally, propagation occurs at a critical energy release rate, Gcrit, or, via equation (2.3) at a critical value of the stress intensity factor, Kcrit. Under tensile ('mode I') loading, in plane strain, this is written as K1c and is referred to as the material's plane strain fracture toughness. For engineering assessment at the macroscale, it is arguably not necessary to delve into the interpretations of K1c, provided that consistent values represent the onset of fracture in different geometrical configurations. For structural steels, it is, however, important to pay attention to microscopically 'brittle' fracture modes, and to how these are affected by microstructural features and by geometrical factors: crack depth, plate thickness, etc.For fracture under 'small-scale yielding' conditions—what might be termed 'quasi-brittle' fracture—the determination of resistance to fast fracture in a structural feature is straightforward. The fracture toughness is determined by measuring the fracture stress and fatigue crack length at failure in a test piece of standard geometry for which the compliance function Y (a/W) is tabulated. For the structural feature, the applied (design) stress is known, and account can be taken of stress-concentrating features and residual stresses to derive the local stresses in areas of interest. It is then possible to assess cracks of different lengths located in these high stress regions and use the combination of local stress intensity factor (calculated from the local stress distribution and the postulated crack length) and the fracture toughness value to determine whether or not the length of postulated crack would lead to fast fracture. A number of iterations allow the critical crack length to be calculated. In most cases, further action is taken to ensure that the fabrication techniques and NDI guarantee that any crack-like defect likely to be present in the structure is much smaller than anything that would raise a concern with respect to fracture.This procedure has to be modified for structural steels under normal service conditions. The 'linear elastic' analysis can be used only for 'quasi-brittle' fractures, occurring under 'small-scale yielding' conditions. This places severe requirements on the sizes of 'valid' test pieces. The standard test piece has width W, thickness B=W/2, and a crack length a, which has to meet the criterion 0.45

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