Summary of Structural Material Failure Theories

Having completed a stress analysis of a part you must decide if it predicts a material failure. Generally, in the elastic range, materials are considered as either ductile (like steel, copper, aluminum, etc) or brittle (like cast iron, glass, concrete).

For ductile materials the two most common theories of failure (you should check both) are the Maximum-Distortional-Energy Theory, also called the Von Mises-Equivalent Stress Theory, and the Maximum-Shear-Stress Theory, also called the Stress-Intensity Theory. Both compare against the yield stress, σ_Y, material property. They predict material failure when either the Von Mises "stress" equals the yield property, $\sigma_Y = \sigma_{VM}$, or when the stress "intensity" equals the yield stress, $\sigma_Y = \sigma_I$.

For brittle materials the two most common theories of material failure are the Maximum-Normal-Stress Theory and Mohr's Theory. Both compare to the ultimate stress property, σ_U, of the material (the stress level where it breaks apart). At all points there are three principal normal stresses, usually called P1, P2, and P3 (for largest, smallest, and mid levels). A positive sign denotes tension. The Maximum-Normal-Stress theory predicts material failure when

$$|\sigma_1| = \sigma_U \ \ or \ \ |\sigma_3| = \sigma_U.$$

If a material is subjected to many cycles of loads you must also check for a Fatigue Failure. Materials have a property known as the endurance limit or fatigue level. The endurance limit is the stress level below which the material can sustain virtually an infinite number of stress cycles (say > 10 million) without failure. Each material has an S-N curve (stress vs. number of cycles to failure). Pick your number of cycles of life (say 1 million), go to the S-N curve and read off the allowed stress for that fatigue life. If your maximum stress exceeds that value your design fails.

Since most students have not yet had solid mechanics (Mech 311) a reference with more details is also provided.