Tolerance for Overload Stress

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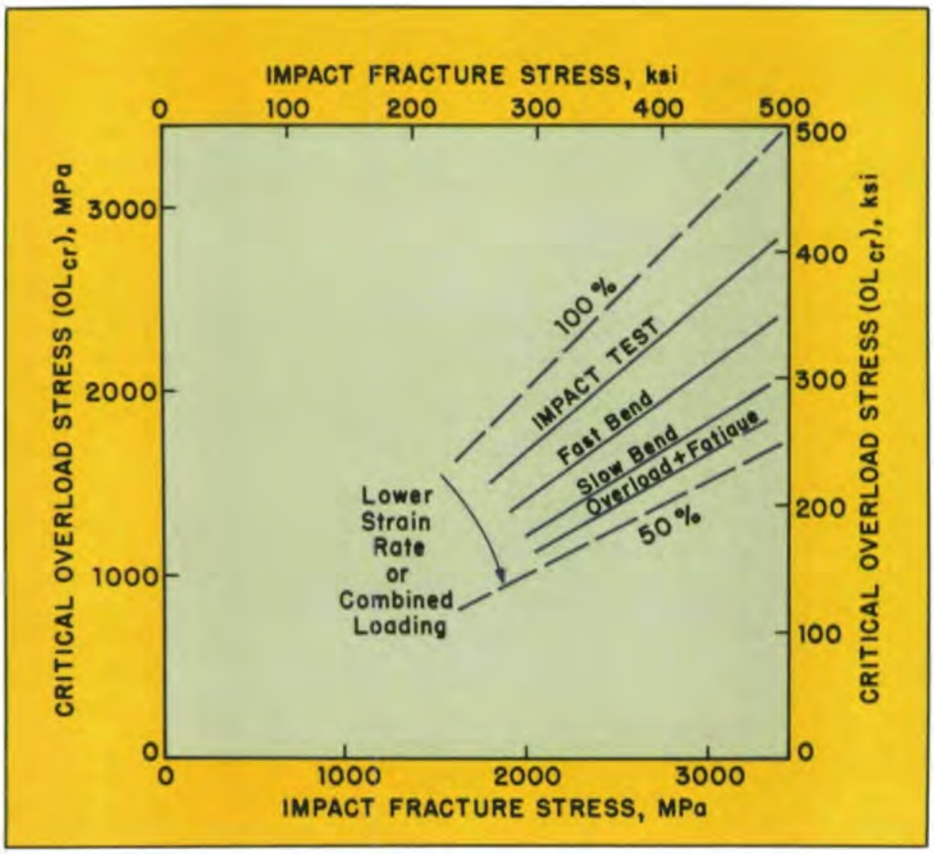

Fig. 1 – Critical Overload Stress Obtained with Various Testing Conditions Compared with Impact Fracture Stress

The performance of carburized components can be improved simply by changing the alloy content of the steel. This fact is particularly useful when a manufacturer becomes tied into a specifically designed assembly and suddenly realizes that some component within the assembly exhibits a higher than desired frequency of failure. Eliminating the problem at this stage by simply changing the steel grade would be a far more economical solution than initiating a change in design. However, the data base available for the selection of an improved grade of carburizing steel does not always make the proper choice of a new grade crystal clear.

There have been several examples in the last few years where the basis for selecting an improved grade of carburizing steel was a parameter defined[1,2,3] as the impact fracture strength of the steel. In most of these situations, the failures were thought to be fatigue related, thus making an alloy steel selection based on an impact property seem inappropriate. However, recent research has shown a connection between fatigue related failure and impact fracture strength.[4] It turns out that all carburized cases have a critical value of stress which cannot be exceeded without causing irreversible damage that, in turn, can result in premature fatigue failure. The failure itself may appear to be fatigue related when, in fact, the initiation event was actually caused by an overload.

Attempts to measure the critical

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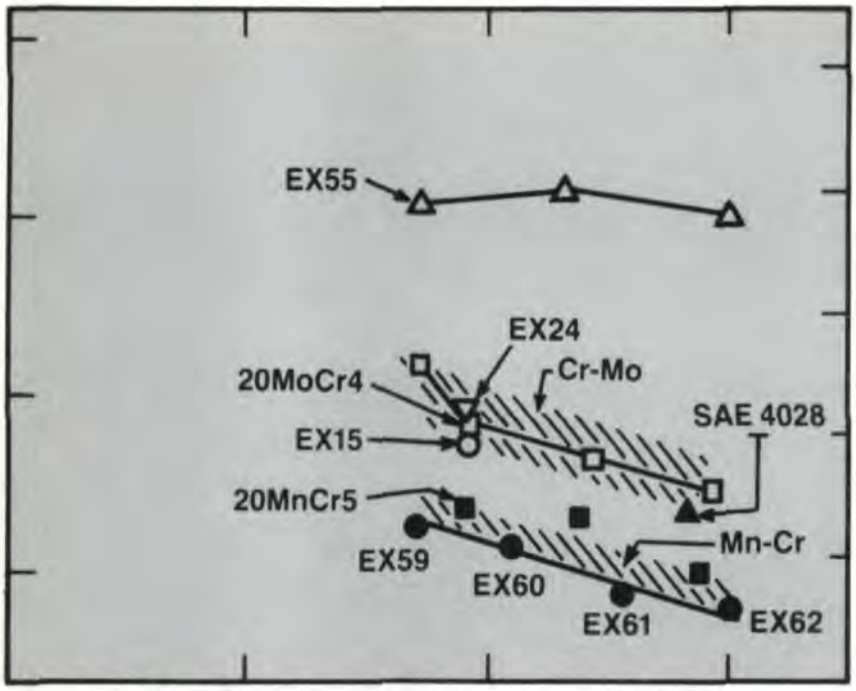

Fig. 2 – Impact Fracture Strength of Various Carburized Steels Plotted Versus Carbon Content of the Core (Reference 4)

overload (OL_{cr}) fracture stress of carburized cases have revealed that this property is strain rate sensitive and also exhibits a damage accumulation effect such that the OL_{cr} value is dependent on the number of fatigue cycles the steel has experienced before the overload stress is applied. The most straightforward method of measuring OL_{cr} is to slowly apply the load until crack initiation is detected.[4] Such a measurement of fracture resistance provides only a relative measure of the steel's ability to resist overload stresses, and it must be realized that fatigue exposure prior to overloading lowers the measured value of OL_{cr}, as can be seen in Fig. 1 where OL_{cr} is correlated with impact fracture strength. Fig. 1 also illustrates the strain rate sensitivity of OL_{cr}, showing increasing values with increasing strain rate. A carburzied case is more likely to initiate an overload crack, if the maximum load is reached with a slow strain rate, than if the same load is applied in impact. Fig. 1 indicates a consistent correlation. Although different for each strain rate, between OL_{cr} and the impact fracture strength. Steels having a high impact fracture strength will also exhibit a high OL_{cr}; therefore, impact fracture strength provides a good relative measure of the steel's ability to tolerate overload stresses during fatigue.

The overload stresses that cause damage are generally above the fatigue limit of the carburized case. Such stresses are not expected to occur, but have been observed to develop for several reasons such as gear misalignment, an object being trapped between gear teeth, higher than expected stress concentration resulting from poor machining or gouging, high stresses encountered during drag start accelerations, and finally, mechanical phenomena such as torsional excitation amplitude stresses that exceed the critical. Regardless of the source, it takes only one application of stress exceeding the critical value to result in premature fatigue failure.

The more commonly used low alloy carburizing steels have OL_{cr} stress values only slightly above the fatigue limit. This fact makes failure analysis difficult. In these situations, a transgranular crack initiation site, usually corresponding to a pure fatigue initiation as discussed previously,[5] is not likely to exist because the OL_{cr} stress, the stress necessary for intergranular fracture, is low and easily exceeded. An example of a steel having a low OL_{cr} value is SAE 4027, and the intergranular nature of the fatigue surface of this steel has been documented.[6] In steels having OL_{cr} stress values significantly above the fatigue limit, the fatigue crack initiation sites are transgranular, thus making failure analysis much easier; i.e., a pure fatigue crack initiation site is transgranular and an overload crack initiation site is intergranular.[5] The remedial action required to correct the situation remains the same for all intergranular crack initiation sites: Change to a grade of steel having a high impact fracture strength.

The magnitude of differences in impact fracture strength to be expected among carburizing steels can be seen in Figs. 2, 3, and 4. SAE 8620 is a commonly used automotive steel, and it can be seen that there are several grades of steel having higher impact fracture strengths such as SAE 4620 + Mo, SAE 4320, EX32, SAE 4817, and EX55. There are also grades of steel having less impact fracture strength than SAE 8620 such as EX59, EX60, EX61, 20MnCr5, and SAE 4028.

The conclusion can be made that, if a given grade of carburizing steel is exhibiting a higher than desired frequency of failure and the fracture appearance of the crack initiation sites are intergranular, the problem can be corrected simply by up-grading to a steel with a higher impact fracture strength. If the crack initiation site is transgranular (excluding microvoid coalescence sometimes observed to occur with single impact fractures), it may be possible to correct the problem simply by shot peening or polishing the surface. An alloy steel change will not generally correct a *pure* fatigue problem unless low fatigue limits were encountered through severe surface oxidation and subsequent alloy depletion of the matrix at the carburized surface.[3]

Parameters other than alloy content such as surface carbon (surface hardness and retained austinite), core carbon (core hardness) and case depth can change the impact fracture strength. The above discussion of relative impact fracture strength presupposes: 1 – that the steels being used have adequate hardenability for the section size and quench, 2 – that the surface carbon results in adequate case hardness, and 3 – that the case depth is sufficient to avoid subsurface crack initiation. The magnitude of change in impact fracture strength, resulting from case depth differences and minor variations in surface carbon and retained austenite, are on the order of that exhibited by changing the core carbon shown in Fig. 2.

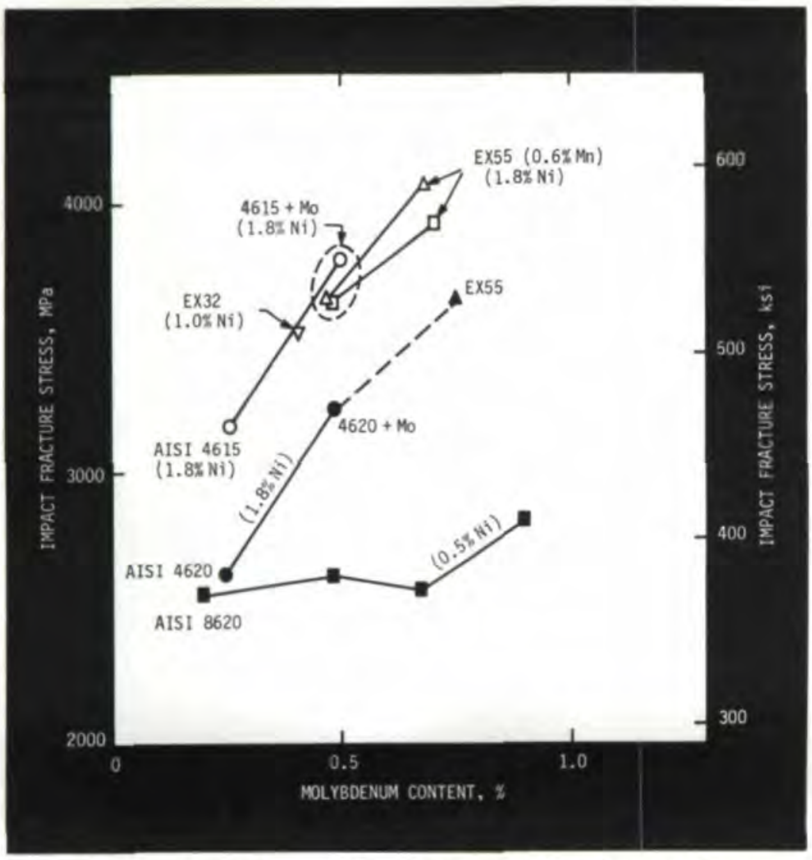

Fig. 3 – (Above) Impact Fracture Stress of Carburized Steels Containing Various Combinations of Molybdenum and Nickel. Open data points are for vacuum-melted heats; solid data points are for air-melted heats. (Reference 3)

References

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Fig. 4 (Below) – Relationship Between Impact Fracture Stress and the Number of Impacts Required for Crack Initiation Under Repeated Impacts at an Energy Level of 4.0 J (35 in.-lb) (Reference 2)