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Fatigue design of highly loaded short-glass-fibre reinforced polyamide parts in engine compartments

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Abstract

The fatigue strength behaviour of a short-glass-fibre reinforced polyamide PA66-GF35 was investigated in detail. The consideration of influencing variables like notches, fibre orientation, temperature, mean-stress and spectrum loading enable the fatigue design of high loaded plastic parts in engine compartments. A design method was developed which is based on FE calculation of the maximum local stress, the appertaining stress gradient and the highly stressed material volume. The method was verified successfully by the example of a fuel rail.

Keywords: Fatigue strength; Temperature; Notch effect; Mean-stress; Highly stressed material volume; Constant and variable amplitude loading

1. Introduction

The low specific weight of plastics offers light-weight design opportunities. Therefore, the application of plastic materials in automotive engineering is increasing [1,2]. Short-glass-fibre reinforced thermoplastics are suited for cost-saving manufacturing of complex parts using injection moulding. Plastic parts are safety components when applied in brake- and fuel-feed-systems. These components must maintain their function during service life at engine-compartment-temperatures of 130 °C and above without failure while withstanding cyclic loading. Therefore, they require to be designed against cyclic service loads considering material properties as well as structural shaping (stress concentration) and environment (temperature). Comprehensive knowledge of the material regarding component-related strength properties is essential for an appropriate and economical design. For this, the application of the local stress concept, verified in a large investigation in LBF [3,4], will be demonstrated by the example of a fuel rail.

2. State of the art for designing plastic components

Until now component design has exclusively used static property data such as ultimate tensile strength, yield strength, failure strain or static creep. These data are not sufficient especially when designing cyclically loaded components. Generally the step from static to cyclic loading applies data obtained with unnotched specimens ($K_t = 1.0$) with unrealistic results as unnotched components do not exist. The failure critical areas of components are locations with notches, i.e. stress concentrations, which must be considered properly with appropriate data.

Drawing conclusions from static material properties with regard to cyclic behaviour and inferring from cyclic property data of unnotched specimens to notched conditions is not sufficient for an evaluation of the real material behaviour and resulted in the past in incorrect conclusions for metals as well as fibre-reinforced materials [5,6]. Usually, in the design of plastic parts empirical reduction

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Nomenclature

D	damage sum, diameter	r	radius
d	thickness	s	length, thickness
E	Young's modulus	ε	strain
I	irregularity factor	μ	Poisson's ratio
K_t	stress concentration factor	n	cycles
K_f	fatigue stress concentration factor	ρ	density
L_s	sequence length	σ	stress
M	mean-stress sensitivity		
N, $\overline{N}$	fatigue life under constant, variable amplitude loading	*Indexes*	
P	probability	a	amplitude
R, $\overline{R}$	maximum stress ratio for constant, variable amplitude loading	m	mean
R_m	ultimate tensile strenght	el	elastic
$V_{x\%}$	highly stressed material volume	eq	equivalent
e	elongation	pl	plastic
j_σ	safety factor	f	failure
k, $\overline{k}$	slope of the Woehler/Gassner curve	s	survival
		th	theoretical
		$x\%$	stress fraction

factors [7,8] take care of influencing parameters like notches, fibre orientation, temperature, aging, mean-stress, multiaxial stress state, loading sequence and scatter.

Finite element analysis determines maximum local stresses, which are then compared with the allowable stresses based on the static tensile strength and the reduction factors. However, this procedure often leads to over-design or even to a rejection of a plastic material as a candidate material based on the suspicion that it would not satisfy the requirements.

This paper presents a systematic procedure, which determines by testing of unnotched and notched specimens the influential parameters mentioned above and allows the transfer of fatigue design relevant data to the component. Thus, structural components can already be evaluated during early design phase with respect to their structural durability.

3. Experimental

As a typical material for highly loaded plastic components in engine compartments like intake manifolds, gears or fuel rails a Polyamide 66 with 35% (weight) of short-glass-fibres (PA66-GF35) was closely examined. Conventional material data are compiled in Table 1.

Fig. 1 shows the injection moulded unnotched and notched specimens axially loaded under constant amplitude loading to derive the Woehler-lines and under random variable amplitude loading, a spectrum with a Gaussían amplitude distribution, Fig. 2, to obtain the Gassner-lines. The notch radii cover an observed range of geometries of plastic components. The notches were obtained during the injection moulding process. The specimens were tested dry as moulded.

Table 1
Material data of PA66-GF35

Properties	Unit	Polyamide 66 (PA66-GF35, dry)
Ultimate tensile strength, R_m	MPa	210
Elongation, e	%	3.0
Youngs's modulus, E	GPa	11.5
Density, ρ	g/cm^3	1.41
Creep strength at 120 °C, 100 h, 0.5% strain	MPa	16
Cost/kg	€	~3
Cost/l	€	~4
Plate stiffness, $\sqrt[3]{E/\rho}$	–	20
Specific strength, R_m/ρ	–	149

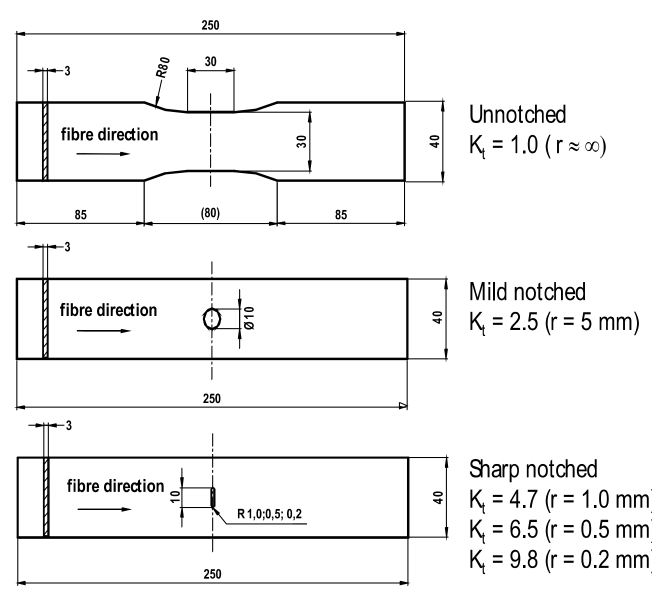

Fig. 1. Specimens with different stress concentrations.