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# Effect of fiber cross section geometry on cyclic plastic behavior of continuous fiber reinforced aluminum matrix composites

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This paper investigates the cyclic plastic behavior of continuous fiber-reinforced aluminum matrix composites (CFAMCs) with different shape of fiber cross section arranged in a square packing geometry. The 2D micromechanical FEM models, composed of elastic undamaged reinforcement perfectly bonded to an elastic-perfectly plastic matrix with a volume fraction equal to 30%, are subjected to off-axis constant macro stress and a cyclic temperature history. Under such load conditions, the matrix undergoes large internal inelastic deformations potentially leading to internal crack initiation as well as macroscopic ratcheting. The computational method, the Linear Matching Method (LMM), is used throughout the analysis for the direct evaluation of shakedown, alternating plasticity and ratcheting behaviors. The effect of the matrix yield stress thermal degradation upon two common design limits, *i.e.*, the reverse plasticity limit and the ratchet limit, is also investigated and discussed, including its influence on the off-axis low cycle fatigue crack initiation.



## 1. Introduction

The cyclic (Han et al., 1995; Llorca, 1994; Sasaki et al., 1994) and monotonic (Corbin and Wilkinson, 1994; Llorca et al., 1991, 1992) mechanical responses of metal matrix composites (MMCs) made up of a metal matrix and ceramic reinforcement have been much studied both numerically and experimentally in the literature. The compelling attention on such materials is due to their excellent combination of low density, high tensile strength, enhanced stiffness, high operating temperatures, wear and creep properties compared with the monolithic metallic counterpart (Suresh et al., 1993).

Continuous fiber-reinforced aluminum matrix composites (CFAMCs) are currently being used in many automotive and aerospace applications such as automotive push rods, brake calipers, retainer rings and flywheels for energy storage, etc., which are often subjected to a combination of static and cyclic conditions (Surappa, 2003). It is well known that the main factors that influence the mechanical response of a general MMC are the mechanical properties of the constituents, the fiber arrangement, the reinforcement fraction volume and its shape (Böhm et al., 1993; Devireddy and Biswas, 2014; Giugliano and Chen, 2016; Hashin, 1983; Srivastava et al., 2011; Xu et al., 1999). The fatigue behavior of MMCs has also been investigated by many researchers with emphasis on the crack propagation rates and low cycle fatigue response under both thermal fatigue and thermo mechanical fatigue. It has been demonstrated that introducing hard ceramic particles in a metallic matrix, the crack propagation rate becomes lower than its unreinforced counterpart (Bonnen et al., 1990). However the existence of the reinforcement in MMCs dramatically reduces the low cycle fatigue (LCF) response of both particulate and fiber reinforced MMCs subjected to off-axis constant macro stress and thermal cyclic conditions (Chen and Ponter, 2005; Giugliano and Chen, 2016; Jansson and Leckie, 1992). It has also been reported that an increase in either fiber volume fraction or particle volume fraction causes further degradation of the LCF response (Giugliano and Chen, 2016; Srivatsan and Auradkar, 1992; Srivatsan and Prakash, 1994). Such a reduction, is mainly due to the mismatch in the thermal expansion coefficient (CTE) of the constituents, the stress concentration at the constituent's interface, the brittle nature of the ceramic reinforcement and the plastic flow constraint within the metallic matrix (Giugliano and Chen, 2016; Jansson and Leckie, 1992; Llorca, 1994; Srivatsan and Prakash, 1994; Uygur and Külekci, 2002).

So far, there have been a number of experimental and numerical studies on the cyclic plastic behavior to characterize the inelastic response of MMCs but, to the best of authors' knowledge, there has been no study concerning the effect of fiber cross section geometry

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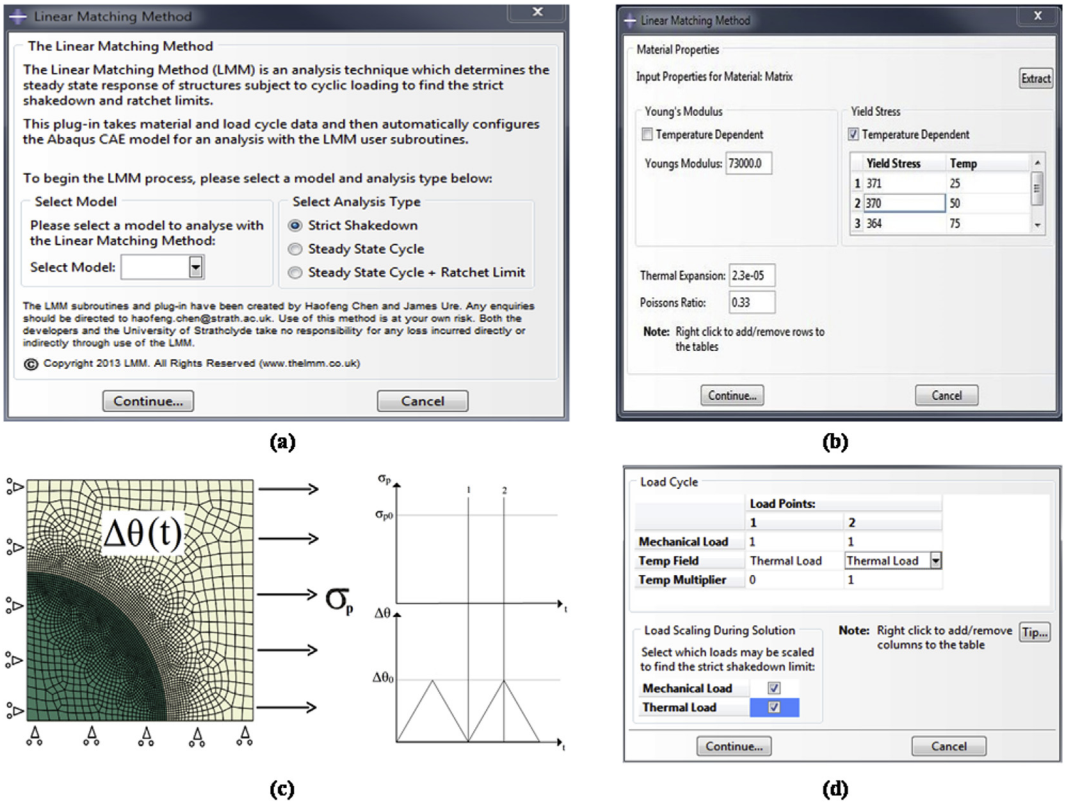


**Fig. 1.** a) LMM main menu for analysis type and model selection; b) material properties selection; c) CAE model with reference loads, d) Load cycle dialog and load scaling options.

on the cyclic plastic behavior of CFAMCs although a deep study on the effect of particulate shape on the cyclic deformation of $SiC_p$/6061Al composites has been reported in (Kang et al., 2007). Thus an investigation of the inelastic response under the combined action of cyclic thermal conditions and off-axis constant macro stress has been carried out numerically using the Linear Matching Methods (LMMs) (Chen, 2010; Chen and Ponter, 2010). Any structure, including composites, that undergo cyclic conditions, can exhibit elastic behavior, shakedown, reverse plasticity or ratcheting depending upon the applied load level. The evaluation of these patterns of behavior may be obtained through a large number of step by step finite element calculations. However, such a numerical procedure can be difficult, very time-consuming and essentially subjective because it depends strongly on the choice of the loading conditions. The latest development of the LMM makes it possible to identify the primary characteristics of the load domain boundaries accurately and efficiently to determine various responses and mechanisms. Indeed, a wide range of applications involving the

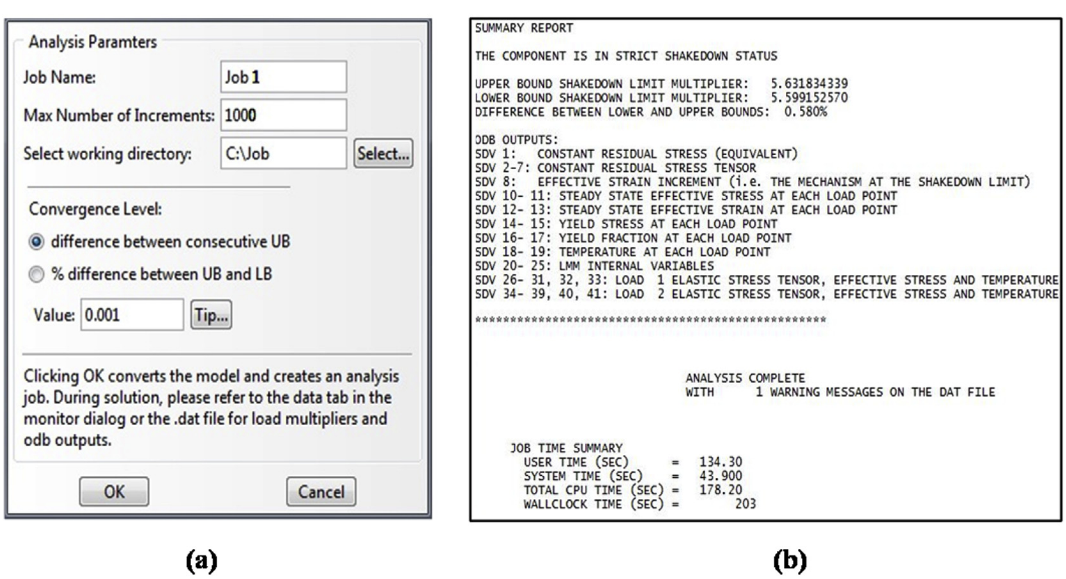


**Fig. 2.** a) Analysis parameters, convergence methods and level menu; b) LMM summary report.