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DEVELOPMENT OF A BIAXIAL TENSILE MACHINE FOR CHARACTERIZATION OF SHEET METALS

© Golovin V.P., Tsaryova A.V.

Samara National Research University, Samara, Russian Federation

e-mail: vladislav.golovin02@gmail.ru

In an attempt to reduce development time and saving costs, virtual manufacturing through finite element analysis has become an almost mandatory step for tool design in sheet metal forming. The accuracy of these numerical investigations is much depending on the chosen constitutive model. Since materials usually undergo multiaxial stressing during forming processes, multiaxial loading experiments are needed to validate the plasticity models to be used in simulations [1]. Among different testing techniques the most appropriate approach for testing sheet materials is to use a cruciform specimen and apply biaxial tension. Several test machines have been developed to produce biaxial loading and can be classified in stand-alone biaxial testing machines and biaxial displacement devices, which are mounted into universal testing machines. To the first group belong machines where the loading system is in-plane with the specimen and is composed by two to four servo hydraulic or screw driven actuators [5]. A main issue of these machines is about preventing off-center shifting of the gauge area of the specimen during the experiment, which can be avoided by synchronizing the displacement of the four independent actuators.

The in-plane solution for the loading system is not the only way to apply the loads. Johnson and Kahn used a deadweight loading system, where for each loading axis a vertical load pan was coupled to a roller chain which passing over a pulley convoyed the tensile force in the horizontal plane of the specimen [3]. However, with this device, the center of the specimen is not stationary and in-plane bending moments are superimposed during the test. Hayhurst solved these issues by means of implementing an elaborate kinematic of the machine, where two opposite circular pulleys per loading axis are linked by a loop of mainly wire rope coupled to one set of the specimen-loading arms [4]. While one pulley was fixed to the machine frame, tensile force was applied to the other and hence to the specimen from a yoke assembly by hanging lead weights on a hinged lever. These testing machines had been successfully employed for biaxial creep testing where steady loads have to be maintained for long periods of time.

Geiger et al. developed an innovative experimental setup for biaxial testing using cruciform specimens having an out of-plane loading system [2]. It consists of an arrangement of four rollers, positioned in a plane at right-angles to each other, assembled into a single screw driven circular punch. Once the cruciform specimen is clamped at the ends of its arms, the punch presses the sample from beneath inducing a biaxial stress state in its center. Different biaxial stress states can be obtained by varying the length ratio of the cross arms of the specimen. Furthermore, an integrated laser source allowed Merklein to determine yield loci at elevated temperatures [6]. However, the identification of hardening parameters beside the onset of yielding cannot be straightforward as load reactions were not detected in the plane of the specimen and bending moments are imposed to the specimen-loading arms.

The second most widely applied approach in biaxial tensile testing is to make use of an existing universal tensile machine equipped with a special tool to obtain a simultaneous displacement of the four clamped ends of the cruciform specimen, though applying a multiaxial loading in its center. Devices of this type are generally joint link assemblies and are more cost-effective compared to stand-alone machines.

A similar design was developed by Tierriault et al., with the difference that the device worked in compression and each of the four grippers were equally displaced in tension by the pantograph [7]. This can be explained by breaking the symmetry of this last arrangement and compensating the yet unbalanced vertical reaction forces. This is achieved by connecting each of the four upper links to a linear bearing system mounted on a steel plate solid with the tensile machine frame. With the cross-head downwards motion, the links convert this movement into horizontal displacement pairwise in opposite direction. A common drawback associated with these link mechanisms is that only one loading ratio at time can be performed.

If a different ratio is required, the links have to be changed and this resulted in being a time consuming solution. In fact, the angles between the links have to assume pairwise different values for every required non-equibiaxial tension. Analysis of the hyperplastic behavior of rubber-like materials engaged this issue proposing an interesting but rather complicated mechanism involving ten between links and solid bars [6]. The main idea behind this solution is that while the displacement of the vertical axes of the cruciform specimen is driven by the cross-head movement of the tensile machine, the displacement in the horizontal direction is determined by adjusting the inclination of two in positive direction divergent oblique bars. Onto this bar, and symmetrically about the vertical axes, slides a second draw bar connecting the grip of one of the two horizontal ends of the specimen. With this arrangement, an upward travel of the cross-head causes a similar upward travel and simultaneously an equal and opposite displacement in the horizontal direction of the two horizontal grips. Even if this biaxial tensile device was proved by testing a material recording normal stress of two orders of magnitude smaller than the case of sheet metals, it has to be considered a valid attempt to implement a selective adjustment of the load ratio.

To sum up, this is an attempt in developing a cost-effective stand-alone machine by adopting solutions from biaxial tensile devices and at the same time overcoming their limitations.

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