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Test Rig of Free End Torsion Effect on Linear Strain

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ABSTRACT

Present work aimed at developing, testing and operating a prototype free end torsion machine for performing torsion tests and checking linear strain in test specimens. The self developed free end torsion machine was used to measure and compute numerical prediction of the Swift effect, i.e. the lengthening of the cylinder during the torsion. The equipment consists of a horizontal torsion machine composed of worm gear, spur gear, bearings, hand wheel, shaft, base plate, column, measuring instruments, chuck mechanism and test specimen. An encoder obtains the torsion angle. Experimental tests were carried out at a constant angular speed that imposed a constant shear strain rate to the test specimen. The torsion tests have been performed on ductile materials - copper and aluminium. The influence of texture evolution was analyzed. Predicted axial lengthening and predicted textures were compared to experimental measurements. A good agreement was obtained between the obtained results.

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I. INTRODUCTION

The torsion of cylindrical bars or tubes is of great importance for the characterization of material properties in the large strain regime. Indeed, under adequate experimental settings, torsion tests remain stable up to very large strains before failure. Contrarily, tensile tests generally become unstable for large strains due to necking, while compression tests are influenced by friction and require large mechanical efforts. However, it is well known that the material behavior during torsion is different from the behavior during tensile or compression tests. Bearing in mind that plastic strains involve dislocation glides which are linked to shearing at the crystal level, the different material behaviors can be explained by the cone of maximum shear planes present in compression and tension compared to the only two maximum shear planes in torsion. Hopefully, crystal plasticity models, by nature, can account for this different material behavior in torsion compared to tension or compression. A particular phenomenon observed during torsion under certain conditions is the Swift effect. It refers to the lengthening or shortening of a cylinder or a tube submitted to large strain torsion in the plastic strain regime. The Swift effect has first been observed by Swift (1947). Lengthening during torsion was previously studied by Poynting (1909, 1912) in the elastic regime. This torsion induced lengthening was found by Weber et al. (2000) to have a purely geometrical origin. Contrarily, a key point concerning the Swift effect is the crystallographic texture evolution due to the large plastic strains involved during these torsion tests. Texture measurements have been carried on before and during experimental torsion processes. Beside, plastic anisotropy models based on texture evolution have been applied for the Swift effect prediction of twisted materials. From these studies, it is admitted that the initial texture of the material and especially the texture developed during the torsion test have a crucial influence on the Swift effect. The rigid body rotation associated to the shearing induced by the torsion process yields to an asymmetric crystal orientation distribution. In turn, the axes of the yield locus are slightly tilted away from the symmetry axes of the tube or the cylinder. The resulting material behavior is lengthening during torsion processes. On the other hand, the shortening observed under particular experimental conditions can be attributed to dynamic re-crystallization during torsion. In order to observe lengthening or shortening of the cylinder or the tube, displacements along its axial direction must be permitted during the torsion process without any axial forces in the specimen. Specific experimental devices are therefore required. This loading is called free end torsion. Analogous axial effect exists in the case of fixed end torsion. As length variations of the tube are not permitted, axial stress develops. Free end torsion and fixed end torsion are related phenomena but they must be analyzed separately as they involve important differences in the boundary conditions of testing. The goal of this study was to model accurately the free end torsion of test specimens of various materials at room temperature. This method accounts for the radial distribution of the shear strain linked to the torsion in the bar. The interaction between the different radial layers of the cylinder and the resulting lengthening were computed. Finally, the complete analysis of the results computed was done.

II. SWIFT EFFECT REPORTED IN LITERATURE

Fig. 2.1 presents the first experimental results concerning torsion induced elongation strains in the plastic regime. They have been reported by Swift (1947) for seven metals.

Author's observations were: ''It will be seen that all seven metals show a general tendency to elongate under severe torsion strain. The final elongation varies from about 1 per cent for carbon steel to over 11 per cent.'' Furthermore, Swift noticed that lengthening was larger for FCC than for BCC metals. According to Swift (1947), the Swift effect has its origin in the interaction between crystals with different orientations. The shearing induced by the torsion is assumed to be accommodated at the crystal level by dislocation glide along well defined slip systems. The hardening behavior on these slip systems depends on the orientation of every crystal with respect to the applied shear strain. High hardened and low hardened grains (depending on their initial orientation) can progressively be distinguished during the torsion. The interaction between these hard and soft grains induces their reorientation, i.e. texture evolution. According to Swift's assumptions, hard grains tend to align their length with the axial direction of the tube or cylinder while soft grains preferably align perpendicular to the axial direction. These re-orientations are subsequently assumed to be at the origin of the observed torsion induced lengthening.

First, it can explain why FCC metals are more subjected to lengthening than bcc metals. The description of Swift (1947) being closely linked to slip system activity, a lower number of permitted slip systems in each crystal emphasizes the phenomenon. Secondly, at high temperatures, a shortening of the tube or cylinder is observed experimentally.The explanation of Swift is based on the work hardening in each crystal; at high temperatures, dynamic re-crystallization occurs and annihilates the work hardening based extension. Furthermore, a non-hardening material like lead is not subjected to the Swift effect even at room temperature. Whereas, room temperature is too low to permit dynamic re-crystallization in steel, aluminium or copper for instance and thus only lengthening is observed.

In fig.2.1,graph is plotted between extension with respect to shear strain and following results were observed

1)The extension in stainless steel is more compared to shear strain

2)In case of aluminum extension and shear strain is less compared to stainless steel

3)Cupro-nickel is having almost linear characteristics between extension and strain

4)Copper shows similar characteristics as above metals until certain temperature , as temperature increases further, the dynamic recrystallization takes place which leads to lateral shear strain

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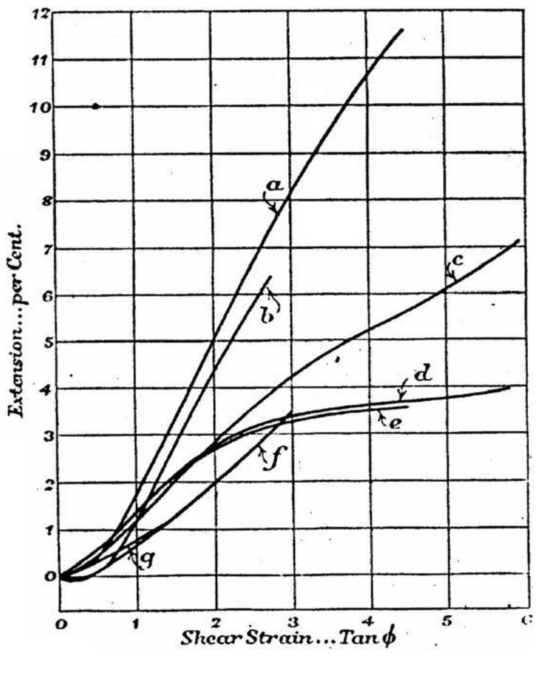

Figure. 2.1. Experimental extension strain as a function of shear strain for 70–30 brass (a), stainless steel (b), aluminium (c), cupro-nickel (d), copper (e), mild-steel (f), 0.5% carbon steel (g), from Swift (1947).

The effect of sample temperature during free end torsion of copper bars was analyzed experimentally. Lengthening was observed during the torsion at room temperature and 125 LC. Lengthening followed by shortening appeared for higher temperatures (200 LC and 300 LC), see Fig. 2.2. By analyzing the texture of the samples at different shear strains, it appeared that the classical texture components observed during shearing were present for the cases at room temperature and 125 LC. These texture components were responsible for the lengthening. For the two higher temperatures, evidences of dynamic re-crystallization appeared after a critical strain. This dynamic re-crystallization was at the origin of the shortening behavior observed during the torsion tests at high temperatures.

The effect of the initial texture on the Swift effect was analyzed during torsion of copper wires. Different initial textures were obtained by annealing at different temperatures. The particular texture components responsible for the lengthening and shortening were identified.

A 7% elongation strain was reported during torsion of 304L stainless steel. This elongation strain was obtained for a torsion induced shear strain of 2.5.

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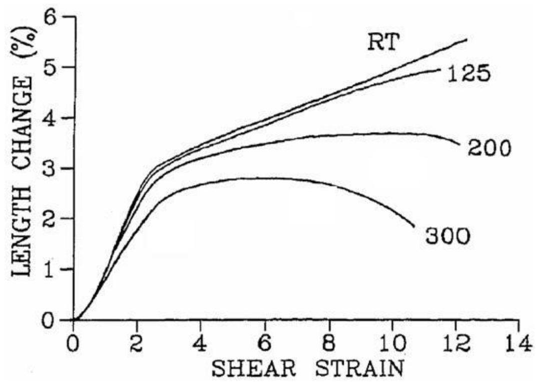

Fig. 2.2 Lengthening during free end torsion of copper bars at different temperatures (LC)

Several authors have developed and applied numerical models for the Swift effect prediction during torsion simulations.

The unconstrained shear of thin walled tubes was simulated using Sachs' hypothesis. Effect of texture evolution was taken into account. The effect of initial texture on the lengthening was analyzed in details by simulating the experiences, where especially designed thin walled tubes with different strong textures were used. The strain rate sensitivity has a very large influence on the Swift effect. It was observed that lengthening for low values of strain rate sensitivity ($m < 0.13$), shortening for high values ($0.167 < m < 1$) and lengthening followed by shortening for intermediate values of m.

From a numerical point of view, it is more complicated to model a cylinder than a tube. Indeed, if the wall thickness of the tube is small enough compared to its mean radius, the analysis of a tube can be reduced to the analysis of its mid-thickness layer. On the other hand, the radial dependency of the material state must be fully taken into consideration for the analysis of a cylinder. Nevertheless, some research works proposed numerical solutions for the Swift effect prediction during torsion of cylinders.

III. EXPERIMENTAL FREE END TORSION TEST RIG

Fig.3.1 shows the developed mechanism and design of free end torsion test rig which consists of base plate, column, spur gear, chuck, bearings , worm gear, hand wheel, shaft, and test specimen.

As seen previously, the aim of this machine development was to perform free end torsion tests on test specimens of aluminium and copper at room temperature. Other materials can also be tested on this machine. For analysis consideration of aluminium and copper is done and results are computed of these material test specimens. The equipment consists of a horizontal machine for torsion test, using a driving electric motor, worm and worm gear, spur gear and pinion, a hand-wheel, a shaft that transmit the rotation to the specimen, a chuck mechanism for holding the test specimen, base and column for support and measuring instruments.

The twist angle is measured by the notations on the hand wheel. An acquisition data system is attached to the equipment which register the values of torque in “Nm” ,the twist angle in “degree” and the length of the test specimen in “millimeters” after twisting on which was possible to determine the longitudinal variation in the test specimen considering different specimens of different materials. For these tests it is necessary that the specimen be submitted to a constant twisting rate which will provide a more reliable result for the longitudinal changes. The test specimen of copper and aluminium are taken of dimensions 10mm diameter and 100mm length. It is held between the chuck mechanisms. It is fixed at one end while the other end is free to rotate as well as free to move in axial direction. With the switching on of the torsion machine the test specimen is made to rotate by giving it torsion at different angles and at different rpm to observe the changes at different conditions.The specimen undergoes various changes, results are obtained concerning different speed and angle of twist.

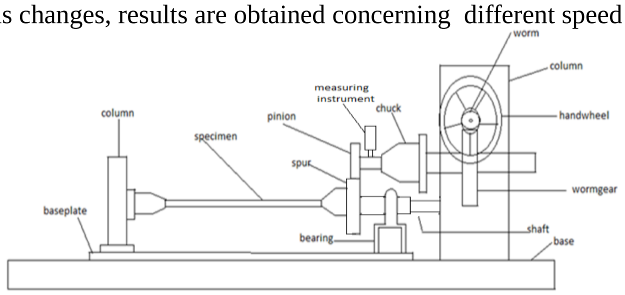

Fig 3.1 Design free end torsion test

In case of aluminum specimen elongation observed and thus results observed during experimentation for specimens of different metals are given in table 1 below.

Table:1

Shear strain	Elongation %	Materials investigated
Up to 6	1-11	Stainless steel,brass, aluminum
0.2-0.3	0.4-0.8	Iron and steel
Up to 5	From 4to3	Copper
0.5	1.6	Aluminum
12	Upto 5.5	Copper at different temperatures

Once the results after the experimentation on different specimens are obtained, the results will be compared with the results that were reported in the Swift effect literature. The analysis of the result with various related parameters will be done and the relation between parameters can be drawn from it.

IV. CONCLUSIONS

In this paper, the free end torsion machine is designed successfully which helped in evaluation and getting results regarding longitudinal length changes at various torsion rates. Thus the results of swift effect reported in literature will be compared with the results obtained from the experimentation on this developed free end torsion machine.

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