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Compression tests of cold-formed plain and dimpled steel columns

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A B S T R A C T

This paper presents compression tests of cold-formed plain and dimpled steel columns. A series of compression and tensile tests were conducted on plain and dimpled steel of different geometries. For each group of geometries the source of material for both the plain and dimpled steel columns was taken from a single coil. Within each group the sections were fabricated either by press-braking or cold-rolled forming. The buckling and ultimate strength of the columns was investigated. The change in strength of the dimpled columns resulting from the cold working associated with the dimpling process was also considered. This paper contains the results obtained when comparing the test strengths of short plain and dimpled steel columns using a compression test. In outlining the work the test setup and testing procedure will be described. Enhancements in buckling and ultimate strengths were observed in the dimpled steel columns-caused by the cold-work of the material during the dimpling process. The results showed that the buckling and ultimate strengths of dimpled steel columns were up to 33% and 26% greater than plain steel columns, respectively.

1. Introduction

Dimpled steel sheets are cold-rolled formed from plain steel sheets by the UltraSTEEL® process developed by Hadley Industries plc [1]. The process uses a pair of rolls which is designed with rows of specially shaped teeth that stretch the surface forming the dimple shapes from both sides of the plain sheet as shown in Fig. 1. The dimpled sheet can then be progressively formed into a desired product by passing it through a series of rolls, arranged in tandem, or by press braking.

The mechanical work done when forming a product section increases the strength of the material in the corner regions of both cold-roll formed and press-brake formed sections and in the flat regions of cold-roll formed sections [2,3]. An essential industrial requirement is that the structural performance of sheet metal cold-formed products be maintained while reducing the sheet thickness to a minimum, thus minimising the material cost. Additional bends in the section such as 'intermediate stiffeners' have been found to improve the material properties of the finished product [4,5] but such improvements are limited. The UltraSTEEL® dimpling process presented, is a method to improve the material and structural performance by imparting a surface deformation to the whole sheet. The first version of the process was developed in early 1980s. Rows of teeth were present as 'helical gears' on the outside surface of the rolls; each gear (tooth) had a flat top and four flanks of an involute form. The current version of the process has a tooth form in which each tooth is entirely radiused to have a rounded surface engaging with the sheet as shown in Fig. 1. This lets the sheet pass between the rolls without damaging the surface and produces broad regions of work hardening [6,7].

Dimpled steel products are increasingly used in a wide range of light building construction. They include wall studs, roofing members, corrugated panels, vineyard posts, windows and door reinforcement. Amongst them, channel shaped products are the most common and widely used as compression and bracing members in such applications [1].

The effect of cold working during the UltraSTEEL® dimpling process on the mechanical and structural properties of the steel material has been the subject of recent investigations through tension and bending tests [7–10]. Tensile and plate bending tests have shown that cold working by the UltraSTEEL® process, increases the yield and ultimate strength and decreases the ductility of metals [7,8]. Experimental bending tests have shown that stud components which are cold-rolled formed from dimpled steel sheet have greater load resistance than a comparable stud component manufactured from a flat steel sheet of the same gauge and identical material [9]. In addition, Finite Element analysis [6,7,10] has shown plastic strains that are developed throughout the entire thickness of the dimpled steel sheet which could be attributable to the increase in bending strength recorded in experimental tests. This was further confirmed by microhardness tests conducted upon cross sections of dimpled

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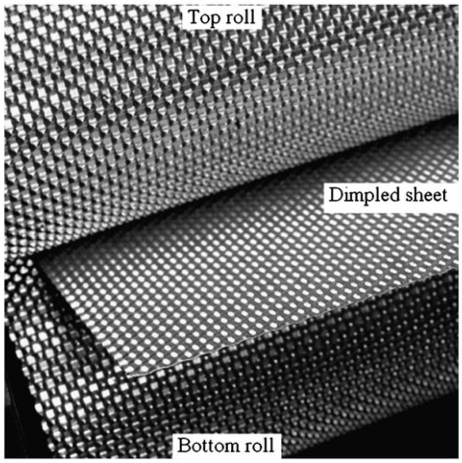

Fig. 1. The UltraSTEEL® process and dimpled steel sheet [7].

samples: they showed that the hardness of the material had increased throughout its entire thickness [6]. The increased strength can lead to a reduction in raw material costs, hence enabling economically advantageous designs. In addition to the economics, the dimpled sheet steel has a unique appearance, increased screw retention, reduced sound transmission and improved performance in fire tests [1,11].

However, neither a standard test protocol nor a specific investigation on compressive tests of dimpled steel columns has been available. Mainly owing to the complex geometry of the dimpled steel, the compressive test of dimpled columns is more complicated than plain columns. One of the greatest challenges is accurately measuring column buckling and ultimate strength. Therefore, it is necessary to establish experimental tests to measure the strength of such dimpled steel columns. This will enable the consequences of the cold work generated by the dimpling process to be quantified. That, in the long-term could allow new design procedures to be established from the acquired data.

In this paper a series of plain and dimpled steel columns, grouped geometrically with each geometric group originating from the same coil of material, were tested in purely axial compression. The tests were performed on plain and dimpled channel columns, fixed at both ends, over a range of different geometries (lengths and cross sections) and materials fabricated by both cold-rolled forming and press-braking. Together with column compression tests, tensile tests of the column material were also conducted to determine the material properties. In this paper, the column specimens are considered 'short columns' as their lengths are greater than three times the greatest flat width of the sections [12] and their slenderness ratio (length/radius of gyration in the direction of the least radius of gyration) is not greater than 54 [13–15]. The objectives of the tests were to determine and compare the compressive strengths between plain and dimpled steel columns. The test results were evaluated by comparing the buckling and ultimate loads with the predicted values based on theoretical and semi-empirical methods.

2. Material and methods

2.1. Test specimens

The column specimens were cold-rolled or press-braked along the rolling direction on plain and dimpled sheets with a nominal Young's modulus of 205 GPa. Typical cross sections of the test specimens are shown in Fig. 2, in which the strain gauge and linear variable differential transformer (LVDT) locations are also illustrated. Measured test section geometries and dimensions are given in Table 1. For dimpled specimens, sectional properties such as moment of inertia and radius of gyration were not available. This is because no calculation methods currently exist to obtain such properties for dimpled specimens.

Different groups of specimens were specified to take into account the variation in the steel material and geometric dimensions. The specimens were organised into six groups of b_f/b_w ratios ranging from 0.31 to 1.95, in which b_f is the width of the flange excluding the corner radius and b_w is the width of the web excluding the corner radii. Each group contains four plain specimens and four dimpled specimens originating from the same coil of material, fabricating by the same forming method and having the same nominal dimensions (Fig. 2). Specimens in test groups 2 and 3 were press-braked whilst the others were cold-rolled. The initial cross sectional width, thickness and length were measured using a micrometre and vernier callipers. For the plain specimens, the initial cross sectional area was calculated from the measured width and thickness. The cross sectional area of the dimpled specimen was measured using the procedure described in [7].

Each specimen was cut to a final length, ranging from 200 mm to 500 mm depending on the test group that the specimen belonged to. To ensure that the two supporting ends were parallel to each other and perpendicular to the loading axis, they were wire eroded normal to the loading axis (longitudinal axis) with a flatness tolerance of ± 0.002 mm (AQ537L model, [16]). This ensured full contact between specimen and the steel end plates. The dimensions of column specimens were chosen to avoid overall buckling and end effects on local buckling. The column length was greater than three times the greatest flat width of the section and its length/radius of gyration in the direction of the least radius of gyration (L/R_{yy} or L/R_{xx}) was kept to less than 54; this was done to prevent failure of the columns due to

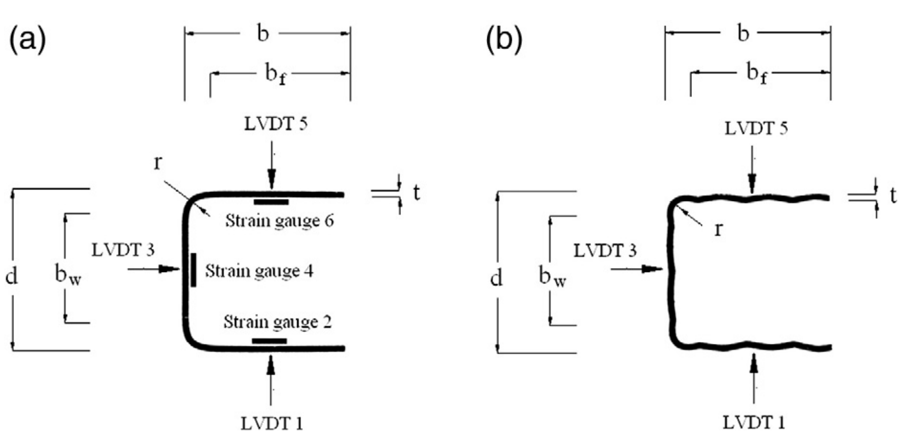

Fig. 2. Cross sections and geometries of column specimens (a) plain section and (b) dimpled section.