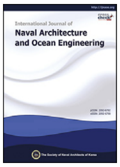

Available online at www.sciencedirect.com

ScienceDirect

Publishing Services by Elsevier

International Journal of Naval Architecture and Ocean Engineering xx (2016) 1–11
http://www.journals.elsevier.com/international-journal-of-naval-architecture-and-ocean-engineering/

On the material properties of shell plate formed by line heating

Hyung Kyun Lim [a], Joo-Sung Lee [b,*]

[a] *Hyundai Mipo Dockyard Co., Ltd., Ulsan, South Korea*
[b] *School of Naval Architecture and Ocean Engineering, University of Ulsan, Ulsan, South Korea*

Abstract

This paper is concerned with investigating the plastic material properties of steel plate formed by line heating method, and is aimed at implementing more rational design considering the accidental limit states such as collision or grounding. For the present study, line heating test for marine grade steel plate has been carried out with varying plate thickness and heating speed, and then microscopic examination and tensile test have been carried out. From the microscopic, it is found that the grain refined zones like ferrite and pearlite are formed all around the heat affected zone. From the tensile test results, it is seen that yield strength, tensile strength, fracture strain, hardening exponent and strength coefficient vary with plate thickness and heat input quantity. The formulae relating the material properties and heat input parameter should be, therefore, derived for the design purpose considering the accidental impact loading. This paper ends with describing the extension of the present study.

Keywords: Line heating; Plasticity and fracture characteristics; Diffusion necking; Microscopic examination; Material properties; Water cooling

---

1. Introduction

Collision, grounding and stranding are major marine accidents which frequently occur in ship and offshore structures. The frequency of marine accidents of ship is increasing with the growing marine traffic and the rapid expansion of ship as a means of transportation owing to the global economic development. Among marine accidents, ship collision takes about 35% of the entire marine accidents (for example web site of KOEM). Especially in case a ship carrying detrimental liquids or oil crash, strand or explode, the leak of its pay load causes serious marine pollution. And it would cause huge environment and property loss as well as life. Along with the regulations of marine ship safety, various international conventions such as International Maritime Organization (IMO), SOLAS, MARPOL, and COLREG have been established to work hard on protecting lives, ships, and marine environment from the marine pollution. It is, however, very difficult to estimate the accurate scale of damage and fracture in case of ship collision because of the great influence of collapse behaviour, tearing pattern, and the ability to absorb collision energy following the collapse of hull structure. As it is well appreciated, for more rational ship structural design, not only the ultimate and fatigue limit states but also the accidental limit state should be properly considered at the design stage.

In real practice, when determining the arrangements and scantlings of a ship's structural members, the accidental loading due to collision is, however, not considered at the structural design stage. In addition to this, accident collision scenarios are not clearly described in the rules of the relevant classification societies, and only the extent of damage due to collisions and groundings are provided in the Harmonized Common Structural Rules, CSR-H (IACS, 2013).

Collision and grounding accidents can be categorized into the internal and the external mechanics. The external mechanics has concerned with the estimation of kinetic energy of

---

* Corresponding author.
E-mail address: jslee2@ulsan.ac.kr (J.-S. Lee).
Peer review under responsibility of Society of Naval Architects of Korea.

http://dx.doi.org/10.1016/j.ijnaoe.2016.08.001

Please cite this article in press as: Lim, H.K., Lee, J.-S., On the material properties of shell plate formed by line heating, International Journal of Naval Architecture and Ocean Engineering (2016), http://dx.doi.org/10.1016/j.ijnaoe.2016.08.001

striking and struck structures, and the internal mechanics has concerned with the dissipated energy due to plastic deformation during collision and grounding. The study on the internal mechanics of collision accident was initiated by Minorsky (1958) and many researches have been carried out in the past few decades. Amdalh (1983) conducted collision test for the bow structure by scaling down and simplifying bulbous bow structures as tubes with circular and elliptical cross-section, and proposed the simplified formulae of estimating crash strength. Numerical simulation methods have been also proposed (for example, see Wisniewski and Koiakowski, 2003). Regarding the fracture criteria, in most studies shear fracture criterion is used in dealing with the collision, contact and grounding problems. Lehmann and Yu (1998) proposed the effect of stress tri-axiality on the fracture based on the fracture mechanics of continuum, and Urban (2003) proposed RTCL model (Rice-Tracey and Cockcroft-Katham model) for the fracture criterion. The common point of these works is that fracture behaviour of material was affected by the stress tri-axiality. Recently Choung (2007) presented the plastic and fracture characteristics of marine grade steels through test and numerical studies. However, in most research, material properties obtained based on results of tensile test for the material without heat treatment have been used. The estimation of damage of striking structure as well as struck structure as accurate as possible is one of the most important tasks for a more rational design. As it is well appreciated, heat forming method usually used in manufacturing the curved blocks frequently found in bow and stern part of a ship, and much heat is inputted during heat forming process. The outer shell plates in bow or stern part of ship usually formed by cold bending process using press followed by heat forming process using line heating, triangular heating and so on. Many researches have been carried out to investigate the physical phenomena or to develop the formulae of predicting thermal deformation of line or triangular heating method (see for example Ha, 2001; Jang et al., 2001; Lee et al., 2002; Shin, 1992). Some were concerned with simulation of plate forming (Lee, 1996, 1997; Nomoto et al., 1990). Research is, however, not much concerned with the change of material properties due to heat forming which is expected to much affect the shape and extents of structural damage subjected to the impact loading due to collision, grounding and so on. In order to predict the extent and shape of damage as accurate as possible, it is, therefore, necessary to investigate the change in material properties due to heat forming of structural part which may be a part of striking structure or struck structure when collision accident occurs.

The paper is aimed at investigating the material characteristics of shell plate formed by line heating far beyond the elastic region in order to implement reasonable design considering the accidental limit states such as collision or stranding. Line heating test for the marine grade steel is carried out with varying the heating speed and plate thickness and with keeping the same heat input condition. Water cooling method is applied as a cooling method to simulate the real practice in plate forming process in real shipyard. Microscopic examination is conducted by taking specimens after line heating test to observe changes in micro-structure at the heat affect zone due to heating. A series of tensile test are conducted in order to get the material properties of marine grade steel far beyond the elastic region when the line heating is applied. The material properties, that is, yield strength, tensile strength, fracture strain, hardening exponent and strength coefficient are extracted based on the results of tensile tests. And through the statistical analysis of above data, plastic strain hardening exponent and strength coefficient are provided, which are basic parameters in Hollomon's constitutive equation.

2. Plastic hardening constitutive equation

Tensile test of steel plate is usually conducted to get the elasto-plastic material properties such as elastic modulus, yield strength, tensile strength, strain hardening exponent, and strength coefficient. Fig. 1 illustrates the typical example of stress-strain curve that can be derived through tensile test. The plastic material property considerably affects the result of the structural analysis when fracture and large strain are accompanied under the accidental load due to collision of ships. The relation between elongation and load can be, however, can be applied until the diffusion necking occurs intensively around some cross-section of member, which is called uniform true stress-uniform true strain.

Nominal strain in a uniaxial tensile test is expressed as Eq. (1).

$$\varepsilon = \frac{\Delta L}{L_0} = \frac{L - L_0}{L_0} \tag{1}$$

Nominal stress is expressed in terms of uniaxial load P as Eq. (2).

$$S = \frac{P}{A_0} \tag{2}$$

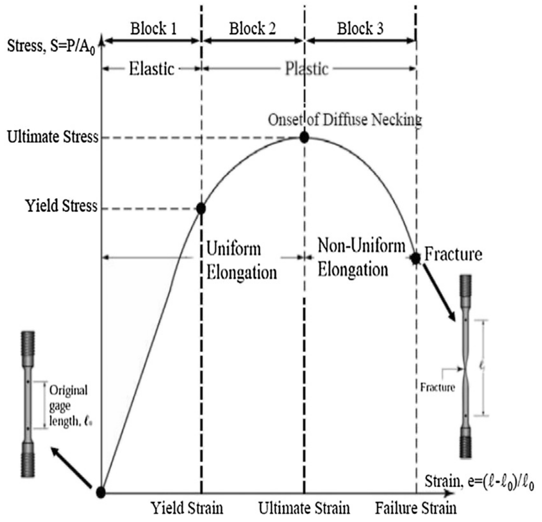

Fig. 1. Engineering stress-strain representing typical three blocks in ductile metal specimen under tensile load (Kalpakjian and Schmid, 2001).

Please cite this article in press as: Lim, H.K., Lee, J.-S., On the material properties of shell plate formed by line heating, International Journal of Naval Architecture and Ocean Engineering (2016), http://dx.doi.org/10.1016/j.ijnaoe.2016.08.001