# Multi-stage hot forming process of shackles

**J. COCHET[a,b] , S. THUILLIER[a] , P.-Y. MANACH[a] , N. DECULTOT[b]**

a. Univ. Bretagne-Sud, EA 4250, LIMATB, F-56100 Lorient, France, sandrine.thuillier@univ-ubs.fr

b. Le Béon Manufacturing, 7 boulevard Louis Nail, F-56100 Lorient, France, n.decultot@le-beon.com

## Abstract :

This study deals with the multi-stage forming process of a sling shackle, investigated with the use of finite element simulation. Used as a lifting connector during Floating Production Unit assembly and provision of supplies for petroleum platforms [Morten, 2010], Wide Body (WB) shackles endure severe working conditions in hostile environment [Ma et al., 2013]. Providing high level of strength and toughness as well as outstanding fatigue behavior, hot forming is one of the main production method of shackles [API, 2010]. Aiming towards process improvement and stronger shackles development, the main purpose of this study is, with the help of numerical simulation, to understand, predict and control all aspects that can be involved in the manufacturing of a WB 125 tons shackle. As shown Fig. 1, shackles can be decomposed into three main domains, namely (i) the jaw, (ii) the body and (iii) the crown.

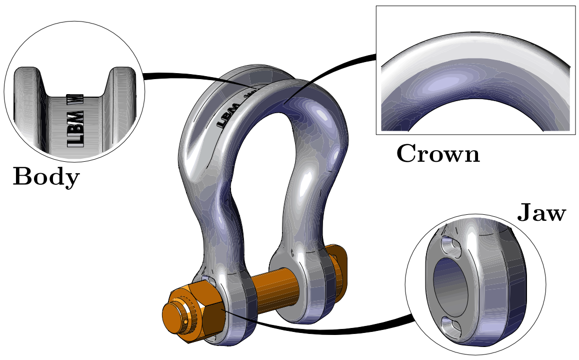
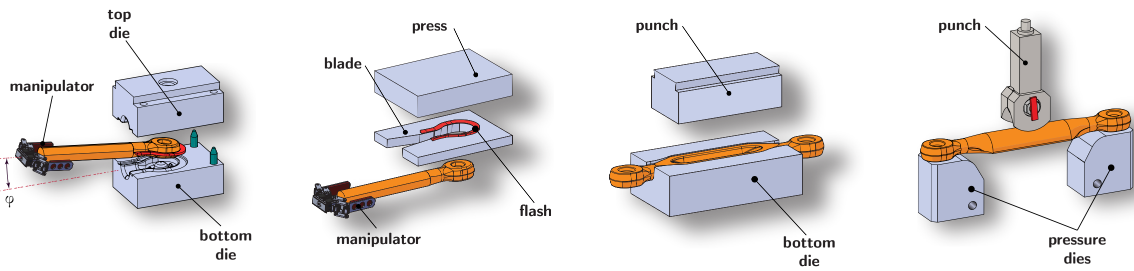



FIGURE 1 – Overall shape of a WB 125 tons shackle and its respective deforming domains

In close collaboration with forging industry Le Béon Manufacturing in Lorient area, forging experiments were carried out on a 0.3 MJ friction drive screw press and at temperatures higher than 900 °C. In order to form both jaws, two successive sequences of closed-die forging and deflashing are performed. It follows an open-die forging stage to form the body. Finally, the crown is obtained using a ram bending process. Outline of these stages are represented Fig. 2.

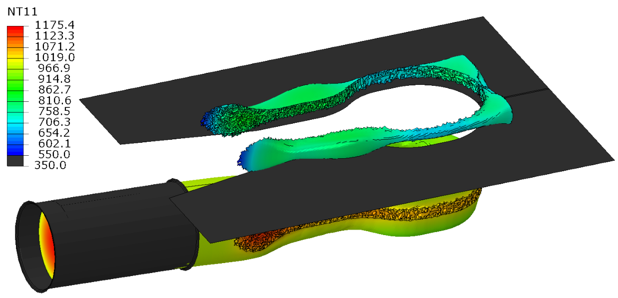



(a) Closed-die forging (b) Deflashing (c) Open-die forging (d) Ram bending

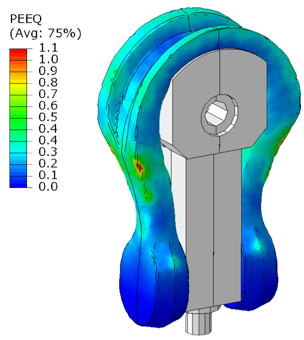
FIGURE 2 – Schematic of the manufacturing process of a WB 125 tons shackle

The numerical model presented herein is developed using a fully coupled 3D thermomechanical analysis and is conducted on Abaqus software. Tools are made of AISI H13 with constant thermophysical properties. Mechanical properties of the 34CrNiMo6 used for the workpiece at temperatures ranging from 800 to 1200 °C and strain rates ranging from 0.1 to 10 $s^{-1}$ were extracted from the literature. To describe the compression behavior, the Johnson-Cook flow stress model has been used. Temperatures, duration and kinematic movements have been recorded over the production of 80 shackles, and forging loads were evaluated by instrumenting strain gauges directly on the mechanical press. A particular methodology has been developed to perform successively the numerical simulation of the various forming operations with a unique workpiece. It combines a sequence of Abaqus/Implicit-HT, Abaqus/Dynamic-Explicit and Abaqus/Static-Implicit. In all simulations, convective and radiative cooling is taken into account and heat transfer between the tools and the workpiece is considered. As in the industrial process, workpiece stability and forging accuracy are obtained with the use of a manipulator modeled as an analytical rigid surface and a combination of springs to account for the recoil and shock absorption. A remeshing method has also been developed to thwart excessive distortion in the flash and the body.

The modeling of the multi-stage manufacturing process of a WB 125 tons shackle has shown good geometric agreement with the mean produced shackles. The mass of flash was experimentally and numerically measured resulting in respectively 1.43 ± 0.11 kg and 1.56 kg. Peak of cumulative plastic strain during closed-die forging, located around the coolest part of the workpiece, corresponds to the actual location of die fragility. The overall dimensions of the numerical shackle was found to be within 5 % of the technical specifications of forging components. In the future, prediction of distortions and behavior in service is necessary. This will be accomplished by developing a metallurgical and microstructural model in order to establish a relationship between phase transformation and heat treatment via cooling and quenching experiments, and SEM/TEM observations.




(a) Temperature gradient in the workpiece after deflashing




(b) Cumulative plastic strain in the shackle after ram bending

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