LINERS FOR SHAPED CHARGES

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Abstract. The penetration potential of shaped charges is proportional to the jet length and the square root of the jet density. The bulk-sound velocities of the liner materials define the maximum possible jet tip velocities. The jet tip velocities and breakup, or particulation, times determine the jet length. For shaped-charge optimisations these parameters have to be considered. After a brief discussion of these issues, this paper outlines the potential of a range of materials for use as possible shaped-charge liners. It is further noted that, as well as the selection of optimal materials, a number of other factors have be taken into account, such as quality of the raw material, homogeneity, and grain-size distribution. Finally, the paper describes the different production possibilities for copper liners, identifying the advantages and disadvantages of each. In particular, the flow-turning process is discussed with its potential for spin compensation.

INTRODUCTION

The shaped charge concept remains a mystery. More than 100 years after the discovery of this effect and after more than 50 years of intensive investigation and research in many laboratories in the world, not all the involved phenomena are fully understood. Certainly the fundamental principles are known and many details can be calculated or predicted with empirically adjusted formulas [1]. One example, however, of a shaped-charge phenomenon that is not well understood is the particulation process, which is an essential feature for optimum performance. The enormous ductility of the liner materials during their jet elongation, with their varied appearances during particulation, is strongly correlated with the microscopic crystal structure, which depends on the original material properties and the processes used to produce the liners.

The liner is critical to the penetration potential of shaped charges, which is directly proportional to the square root of the density of the liner material [2]. Penetration is also directly proportional to the maximum length of the jet, which is given by the product of jet-tip velocity and the particulation time. The jet-tip velocity is dictated by the bulk-sound velocity of the liner material. The particulation time, or breakup time, of the jet is given by the ductility of the liner material, which is essentially influenced by the crystal structure [3]. However, it is not clear why the crystal structure of the liner material is so important for the break-up time of shaped-charge jets [4]. At first the liner material is extremely shocked by the detonation pressure of a few hundred kilobars and accelerated. Then the jet is squeezed out in the collapse process from the inward flowing liner mass, again under extreme high pressures. Further the jet is elongating under very high strain rate conditions. It is surprising that the jet is still influenced by the original crystal structure during the particulation processes. Besides the break-up time of the individual particles, their geometry has a strong influence on the performance. If, instead of ductile necking, the particles break under shear failure then the penetration performance can be drastically reduced with increasing stand-off, because the jet particles are tumbling and moving transversely.

The crystal structure also strongly influences the collapse process itself, as demonstrated by the spin compensation of special liners with omnidirectional asymmetries [5]. An excellent summary of shaped-charge liner materials, including the resources of the raw materials, their properties and costs is given by Buc [6].

JET FORMATION, ELONGATION AND PARTICULATION

The liner material of an axi-symmetric shaped charge is accelerated along the axis of symmetry by the very high pressure of the detonating high explosive charge. In the process of collapsing, the jet is squeezed out with possible tip velocities of 9,000–12,000 m/s, depending on the shaped-charge geometry and liner material, and the slug is formed with velocities of a few 100 m/s. Due to the velocity gradient between the jet tip and the slug, the jet—beginning with a strain rate of 10^4/sec and later with 10^3/sec—elongates up to 1,000% or 2,000% longer than the length of the liner (of a good copper material) before it breaks up into the discrete jet particles. We do not currently have a plausible explanation of the incredible strain potential of the different materials during the jet formation and the enormous stretching potential.

The length of the jet, and therefore the late particulation on one hand as a function of the density of the jet, define the theoretical possible penetration depth P. For a particulated jet the following simple equation is valid [2].

$$P = \left(v_{j0} - v_{j,min}\right) t_P \cdot \sqrt{\rho_j / \rho_t} \qquad (1)$$

The maximum depth of penetration P is given by the velocity difference of jet tip v_{j0} and the cut-off velocity $v_{j,min}$, the particulation time t_P and the square root of the ratio of the jet density ρ_j to target density ρ_t. The maximum jet tip velocities for the different liner materials cannot be increased indefinitely, but are limited by a factor of the bulk-sound velocity of the liner material. The so-called inflow velocity of the liner material has to be smaller than the shock wave velocity of the material under the pressure in the collapse zone. As a first rough rule, the maximum achievable jet tip velocity is 2.34 times the bulk sound velocity of the liner material. The minimum efficient jet velocity or cut-off velocity $v_{j,min}$ depends essentially on the precision of the jet, that is on the straightness of the jet and on the particulation process. The particulation process produces tumbling and transverse moving particles, which are essentially influenced by the crystal structure of the liner. If the residual jet portions do not hit the entrance hole or touch the narrow crater walls and vaporise, then they are not able to transfer penetration potential into penetration depth. From experience, break-up time itself strongly depends upon the crystal structure of the