OPTIMISING THE MECHANICAL PROPERTIES AND MICROSTRUCTURE OF ARMOURED STEEL PLATE IN THE QUENCHED AND TEMPERED CONDITION

by

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To my lovely wife Aimée,
Our daughters and son Gentille, Candide and Artig
And Nelie

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ABSTRACT

The effect of the chemical composition, austenitisation temperature and tempering temperature and time on the mechanical properties and on the ballistic performance of martensitic steel armour plates was studied.
It was established in this study that the mechanical properties and the ballistic performance of martensitic steels can be optimised by controlling the chemical composition and the heat treatment parameters. However, it was observed that for a given chemical composition of the steel the heat treatment parameters to be applied to advanced ballistic performance armour plates were different from those required for higher mechanical properties. Such a contradiction rendered the relationship between mechanical properties and ballistic performance questionable. Systematic analysis of the microstructure and the fracture mechanism of some martensitic armour plate steels was carried out to explain the improved ballistic performance of steels whose mechanical properties were below that specificied for military and security applications. It was inferred from phase analysis and its quantification by X-ray diffraction, characterisation of the martensite using scanning electron microscopy, transmission electron microscopy and atomic force microscopy that the retained austenite located in the plate interfaces and on grain boundaries of the martensite was the main constituent resisting localised yielding during ballistic impact on thin steel plates.

A part of the kinetic energy is transformed into adiabatic heat where a reaustenitisation of the plate martensite and the formation of new lath martensite was observed. Another part is used to elastically and plastically deform the ballistic impact affected region around the incidence point. Dislocation pile-ups at twinned plate interfaces suggest that the twin interfaces act as barriers to dislocation movement upon high velocity impact loading. The diameter of the affected regions, that determines the volume of the material deforming plastically upon impact, was found to vary as a function of the volume fraction of retained austenite in the martensitic steel. Upon impact, retained austenite transforms to martensite by Transformation Induced Plasticity, the “ TRIP ” effect. High volume fractions of retained austenite in the martensitic steel were found to yield low values of the ratio yield strength to ultimate tensile strength (YS/UTS) and a high resistance against localised yielding and, therefore, against ballistic perforation.

A Ballistic Parameter was proposed for the prediction of ballistic performance using the volume fraction of retained austenite and the thickness of the armour plate as variables.

Based on the martensite structure and the results of the ballistic testing of 13 armour plate steels a design methodology comprising new specifications was proposed for the manufacture of armour plates whose thicknesses may be thinner than 6mm.

KEYWORDS: Martensite, retained austenite, ratio yield strength to ultimate tensile strength (YS/UTS), ballistic performance, ballistic parameter, reaustenitisation, martensite start temperature.