the bainite plate thickness and as the transformation temperature is reduced the thickness of the plates decreases. Therefore, it can be understood that the aim of the heat-treatment process is to reduce the transformation temperature in order to promote thin plate formation. However, this reduction in transformation temperature results in a reduction in the rate at which bainite forms (in the order of hours to years depending on the carbon concentration). For 1 wt% carbon it is predicted to take approximately a year (Garcia-Mateo et al., 2003). This is the key disadvantage of super bainitic steels. However, alloying with cobalt or aluminium accelerated transformation and in future research the possibility of rapid transformation could be produced by controlling manganese content (Caballero and Bhadeshia, 2004).

2.4.5.2 Flash bainitic steels

A US company (SFP Works, LLC) developed an evolutionary steel thermo-processing technique, called the flash bainitic process, in 2007. It is claimed to possess tensile strengths from 1100 to 1900 MPa, with 8–9% elongation. Commercial off-the-shelf steel sheet, plate (up to 61 mm wide and 6.6 mm thick), and tubing (12–63 mm in diameter) can be transformed to flash bainite. Through rapid heating and water quenching, a bainitic microstructure is produced very rapidly in a continuous rolling process (Fig. 2.36).

Work conducted in the US showed that flash bainitic armour (FBA) is superior to RHA and conventional HHA (Lolla et al., 2011). FBA4130, for example, appears to offer a 40% mass reduction over RHA for armour piercing threats (Fig. 2.37) and 34% less areal density than conventional HHA against FSP threats (see Fig. 2.38). However, because of the processing limitations, the thicknesses of useable steels are restricted to less than 6.6 mm.
Twinning-induced plasticity steels

The development of TWIP steels has been mainly driven by the automotive industry. TWIP steels have an excellent combination of high strength and formability (ductility), which is particularly attractive for structural reinforcements and energy absorption parts.

TWIP steels, which were developed from the late 1990s, have excellent ductility, high work hardening rate, and a significantly enhanced capability to absorb energy.
upon impact, while maintaining stability and strength of components. TWIP steels normally comprise 20–30% manganese and small quantities of carbon, aluminium and silicon, which causes the steels to be fully austenitic at room temperature. The principal deformation mode is twinning inside the grains and the tensile elongation can be as high as 100%, while the ultimate strength can be above 1000 MPa (Bouaziz and Guelton, 2001; Zhen-li et al., 2009).

Compared with TRIP steels, which have been on the market since the 1980s, TWIP steels have greater reserve ductility and a higher work hardening rate. Their ductility stems from stacking faults in its face-centred crystal lattice. If an extra two stacks of atomic planes are introduced to the lattice from above, it disturbs the regular sequencing of the atomic planes, forming a stacking fault on a mirror plane and creating regularly mirrored sections of crystal. The effect is called twinning, which causes a high value of the instantaneous hardening rate as the microstructure becomes finer and finer. The resultant twin boundaries act like grain boundaries and strengthen the steel. Therefore, once a particular volume of steel has started to deform, its yield strength rises such that deformation spreads out to neighbouring volumes. The full material participates in deformation and hence energy absorption.

However, whilst their energy-absorbing capacity is attractive to the automotive industry, their relatively low yield strength limits their application as an armour material.

### 2.4.5.4 Transformation-induced plasticity steels

TRIP-assisted steels have a microstructure that is a mixture of allotriomorphic ferrite, bainite (∼20%) and retained austenite (∼10%). During plastic deformation and straining, the metastable austenite phase is transformed into martensite. This transformation enables enhanced strength and ductility, with typical ranges of 500–1000 MPa for tensile strength, and 15–30% for elongation. A typical TRIP steel would have a composition based upon 0.1–0.4% C with 1–2% of each of