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INCUBATION TIME AND GROWTH PATTERN OF MARTENSITE UNDER A SHORT STRESS PULSE

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A plate-impact recovery technique is employed to subject specimens of a Fe-31%Ni-0.02%C alloy to a single tensile pulse in uniaxial strain, at a temperature of M_S + 10°C, inducing martensitic transformation. The entire transformation process, from inception to nucleation, to partial growth, and to fully grown lens is captured by adjusting the pulse duration. It is found that the annealing twin boundaries are favored sites for tensile stress-wave-induced martensitic transformation, and that there is an incubation time of somewhat less than 80ns under a 1.5GPa tensile pulse before transformation takes place. It is found that the early growth of the martensite is like an arrow or a needle, always found on a grain or an annealing twin boundary.

1. INTRODUCTION

Martensitic transformation, named after Adolf Martens, is a phase change through diffusionless cooperative atomic movement. The temperature at which spontaneous transformation occurs upon cooling, is called the martensite start temperature, denoted by M_S ; see, e.g. Kaufman and Cohen[1]. The details of the transformation are rather complex and have not been fully understood. Tensile stresses can induce martensitic transformation at temperatures above M_S. This can occur even though the stress may be well below the yield stress of the parent phase. Patel and Cohen[2] have demonstrated that quasistatically applied hydrostatic pressure decreases the M_S temperature, whereas tensile stress increases this temperature, enhancing the transformation. This was studied by Meyers[1], using a tensile pulse of adequate duration for nucleation to take place. He suggested that the thickness of the martensite-free layer may be used to calculate the time required for nucleation. Thadhani and Meyers[4] have investigated the kinetics of martensitic transformation in a Fe-32wt%Ni-0.035wt%C alloy, induced by tensile stress pulses. It is observed that the martensite fraction transformed increases with a decrease in temperature above M_S and an increase in pulse duration. Chang and Meyers[5] extended the work with an Fe-22.5wt%Ni-4wt%Mn alloy which exhibits a very sluggish isothermal transformation. They suggest that nucleation could be produced by a gradual lattice shift in a thin region oriented along the habit plane and that growth would proceed laterally, starting form the habit plane, once the transition occurs at the interface.

Recently, a novel technique has been developed at the University of California, San Diego, to produce tensile pulses of controlled duration in normal plate-impact experiments, by providing a controlled gap between the sample and the momentum trap[6]. In this technique, a portion of the sample can be subjected to a single tensile pulse, and then the sample recovered without having been subjected to additional tensile stresses. This technique has been used by Sano[7] to induce martensitic transformation at a temperature of M_S + 10°C, by tensile stress pulses of 1.5GPa, and durations insufficient for the full growth of martensite lenses. In this manner, the existence of an incubation time of somewhat less than 80ns is established for an Fe-31.8wt.%Ni-0.020wt.%C-alloy. The martensite lenses are captured at their inception and partial growth stages, emanating from annealing twin boundaries.

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2. EXPERIMENTS

Normal plate impact experiments with and without a momentum trap, were performed at the temperature M_S + 10°C, first establishing that, with a 1.56GPa tensile pulse of sufficient duration, martensitic transformation does occur, and then controlling the pulse duration through a controlled gap between the sample and the momentum trap, in order to control the inception and growth of martensites. Figure 1 schematically shows the effect of the gap in creating a tensile pulse. By controlling the size of the gap and the thickness of the flyer plate relative to the target, the size of the tensile pulse and the region through the thickness of the sample subjected to this pulse are controlled. Pulse durations of 79 and 105ns have been achieved with a momentum trap, and 191 and 244ns were used without a momentum trap. The target assembly is schematically shown in Fig.2.

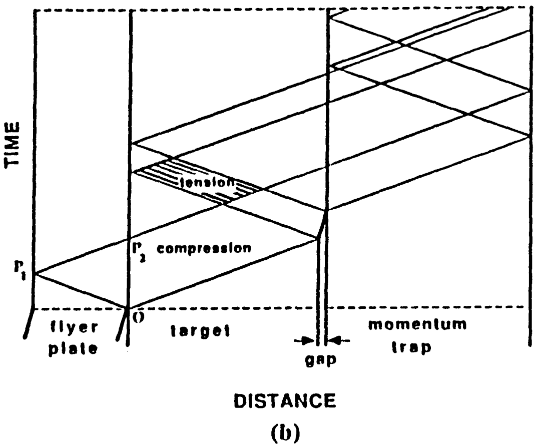

FIGURE 1
Distance-time plot showing tension pulse generated by a gap between the target and the momentum trap.

The gas gun is 5.8cm in diameter with a 114.3cm long barrel and an end experimental chamber, which are evacuated to below 250 milli-torr. Figure 3 schematically shows this gas gun. The alignment of the target specimen and the flyer plate is accomplished using an auto-collimator, attaining an alignment accuracy of 0.02 milli-radian. The impact velocity of the projectile is measured by three magnetic speed sensors placed at half-inch intervals at the exit end of the barrel. The tilt of the target relative to the flyer plate at the impact instant, is measured by the tilt pins properly attached to the target. The tilt angle is obtained from the impact velocity and the differential time associated with the pins. In this study, tilt angles were all below 1.2 milli-radian. The tilt pins also provide the triggering of the data acquisition system.

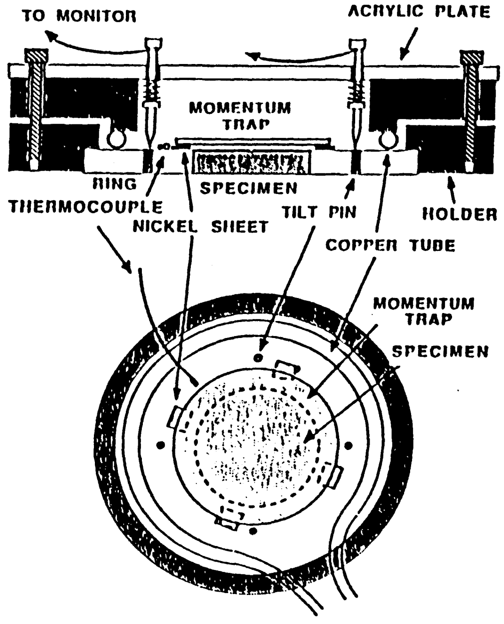

FIGURE 2
Schematic representation of the target assembly.

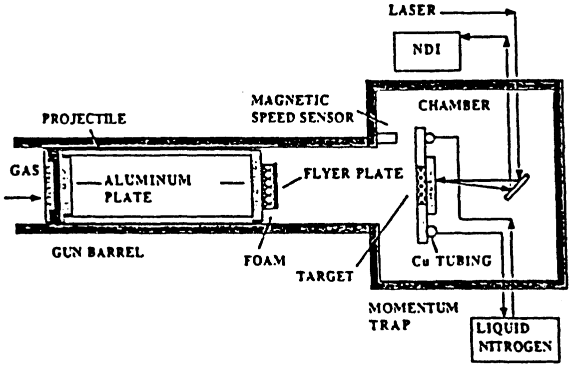

FIGURE 3
Schematic representation of the gas gun.

The rear surface motion of the momentum trap or the target (when there is no momentum trap) is measured by a normal displacement interferometer[8]. An argon laser operating in a single frequency mode, with a wavelength of 514.5nm is used. The data are recorded and analyzed by a LeCroy high-speed wave-form digitizing system.

3. RESULTS AND COMMENTS

It was established that impacts producing 1.4GPa did not induce martensitic transformation, whereas impacts producing 1.6 and 1.7GPa did. The micrographs of a central region of specimens impacted at the same stress level, but with tensile pulse durations of 244ns without a momentum trap, and 105ns and 79ns with a momentum trap, are shown in Figs. 4(a,b,c) respectively. The transformation product is localized in the center of the target specimen. This non-uniform martensitic distribution agrees with the predicted distribution of martensite, induced by a tensile pulse. According to this, the localization occurs because the duration of the tensile pulse is maximum at some region near the center of the target, depending on the thickness ratios of the flyer plate and the target, and the gap between the target and the back momentum trap.

No fully transformed martensite is observed in the target specimen impacted at a tensile pulse duration of 79ns, but very small partially grown lenses are detected, as shown in Fig. 4(c). On the other hand, with a pulse duration of 244ns, fully developed martensites are seen, but no partially grown lenses as shown in Fig. 4(a). With a tensile pulse duration of 105ns and with a momentum trap, we then succeeded to capture martensites from their inception to partial and full growth states, as seen in Fig. 4(b). These results strongly support the duration-time dependence of martensitic transformation in the Fe-32wt%Ni-0.020wt%C alloy.

As shown in Fig. 5, the early growth of the martensite in the specimens is like an arrow or a needle, and is always found on the grain boundaries and on the annealing twin boundaries. Annealing twins are a prominent feature of the microstructure of many recrystallized face-centered cubic metals and alloys. These usually appear as parallel-sided

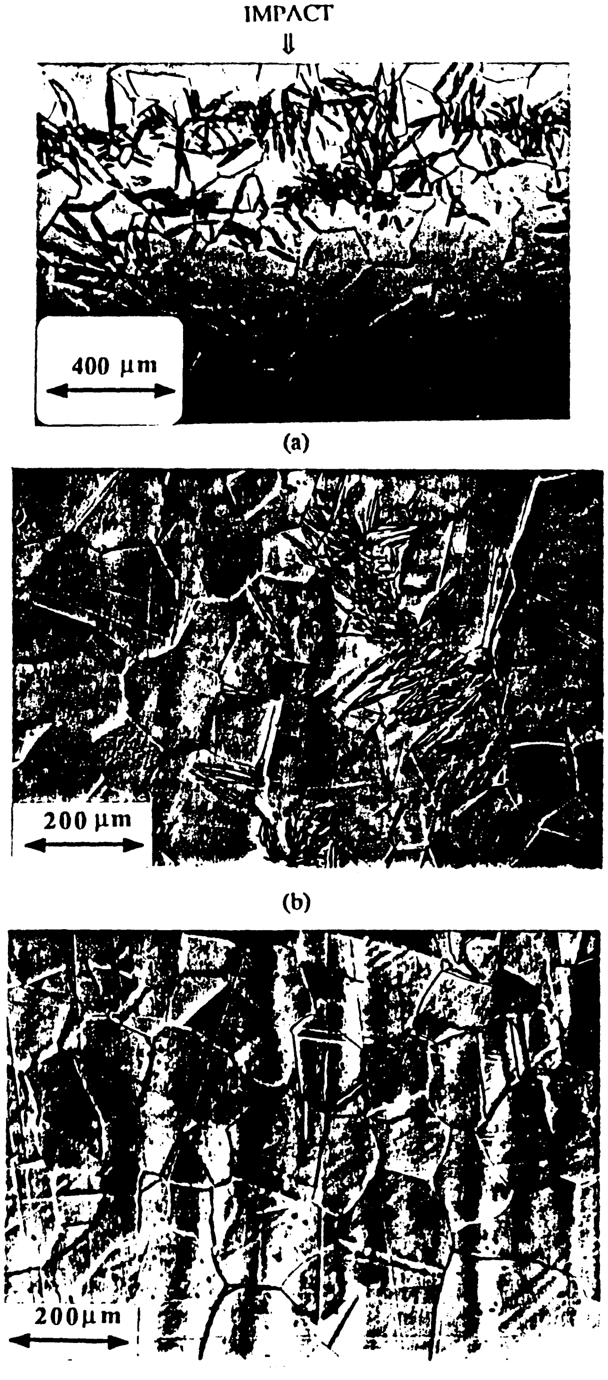

FIGURE 4
Micrograph of cross sections of recovered specimens subjected to tensile pulse durations of: (a) 244ns (without momentum trap; (b) 105ns (with momentum trap); and (c) 79ns (with momentum trap).

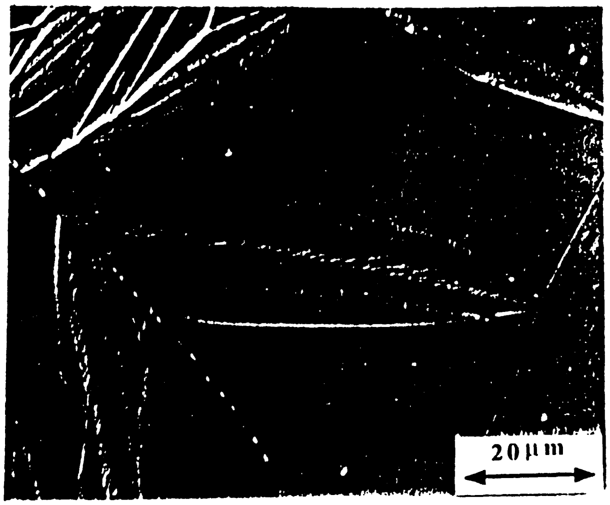

FIGURE 5
Impacted sample under tensile pulse duration of 105ns (with momentum trap), showing arrow-like early growth of martesite from annealing twin boundaries.

bands bounded by coherent $\{111\}$ planes. A face-centered cubic twin is equivalent to a growth fault. If stacking faults exist in the deformed matrix, there is a favorable situation for twin formation when a growing grain reaches a fault[9].

These needles have their extremities on the grain boundaries, and they occur symmetrically with respect to the boundaries. The needles on the same grain boundaries are oriented in the same direction, and those on the adjacent twin boundaries are oriented in the opposite direction.

Figure 5 shows the boundaries where needles and fully-transformed martensite coexist. The martensite nucleation and growth do not seem to be the same process. The martensite seems to grow from some region of the needles along the habit planes. No martensite was seen to have transformed beyond the grain boundaries. Martensites frozen half-way through the process of growth were observed, appearing like notched leaves, with notches parallel to each other. These notches actually consist of many plates of the same orientation with a (121) habit plane[10].

From these observations, the nucleation and growth mechanism of martensite may be explained as follows. First, the nuclei of martensite emerge at grain or twin boundaries and grow along the habit plane. Then, a mid-rib grows from the needles along a habit plane. Finally, small martensite plates of the same orientation as the habit plane grow from the mid-rib in a certain direction.

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