PROBLEMS ASSOCIATED WITH EXPLOSIVE FORMING OF METALS

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I presented at your 1960 meeting, a review of the present state of knowledge with respect to the reaction of metals to explosive loading. This paper discussed such phenomena as fracturing, work hardening, and shaping of metals using explosive charges. The treatment was general in most respects without special emphasis being given to specific applications. As a consequence of my paper, a number of members of Division 20 developed an interest in the possibility and practicality of accomplishing with explosives the physical property modifications normally accomplished by shot peening. At the time there was not enough data to assess the usefulness of the explosive method. Subsequent to the meeting, Mr. Jelsch of Rockwell-Standard indicated an interest in pursuing the matter further and for more than a year supported a modest effort at the Colorado School of Mines Mining Research Laboratory, the work being done in cooperation with Mr. Komarnitsky, a consultant to Rockwell-Standard. I would have been delighted to say that we have now developed a method for explosively treating metals which results in the same material property changes as mechanical working, but our experiments did not conclude in this successful fashion. In view of the very great interest originally shown, it is appropriate to present our negative results and to discuss some of the problems which we encountered.

Previous experience has indicated that the physical properties of metals can be modified either by severely impacting the metal or detonating, in intimate contact with it, a layer of explosive. Numerous experiments along these lines have been separately carried out by John Pearson, of the U.S. Naval Ordnance Test Station, Inyokern, California, and Dr. G. E. Dieter, of the duPont Engineering Laboratory. Their results show clearly that the effect of explosive loading is to increase yield strength, increase the ultimate strength, and decrease the ductility. Thus, the yield strength of mild (1015) steel plates was found to increase from 33,000 psi to 74,000 psi, with a decrease in elongation from 41 percent to 13 percent, when a 3/8-in thick layer of explosive was detonated on the surface of a 1/2-in thick plate. Similarly treated 4130 steel, having an original yield strength of 39,000 psi, developed an 84,000 psi yield strength with elongation going from 35 percent to 17 percent, and ultimate strength increasing from 78,000 psi to 87,000 psi. Rolled manganese steel changed its properties as follows: Brinell hardness increased from 200 to 370; yield strength, from 58,000 psi to 126,000 psi; tensile strength, from 134,000 psi to 182,000 psi; elongation decreased from 48 percent to 37 percent; and reduction in area remained constant at 40 percent. From these data, it would appear that explosive working in certain instances is an effective agent.

Our own experiments were directed primarily at developing increased surface hardness and increased fatigue life. Almost all of the tests were carried out on steel blocks, annealed 1020 in some cases and hardened 4160 in others, the latter blocks being heat treated and supplied by Rockwell-Standard. The explosive in all cases was a layer of duPont sheet explosive, EL-506A-2 or -4. The -2 explosive is 0.084 in thick and contains 2.0 gm of explosive/sq in of sheet; the -4 sheet

explosive is 0.165 in thick and contains 1 gm explosive/sq in of sheet.

The main problem from an experimental point of view which developed in connection with the tests was that the blocks, which were about 1/4 in x 11 in x 1 in thick, fractured extensively as a consequence of reflections from free surfaces of the intense transient stress disturbances generated by the explosive charges. After much experimentation we were successful in eliminating most of this deleterious fracturing. The stratagem, a technique directly attributable to a clear understanding of the salient aspects of stress wave propagation, was to trap the momentum of the transient stress disturbance and summarily dispose of it. At first, thin steel plates, 1/16 and 1/8 in thick, were placed against surfaces of the block other than that against which the explosive was placed, the thought being that these plates would carry off with them as they were hurled from the block the momentum of the transient disturbance. And, in fact, this proved to be the case. However, the fabrication and affixing of these thin plates did not appear to be a feasible production technique and in the end we substituted for them a thick layer of white lead paste. This heavy paste functioned as well as the steel throw-off plates and was adopted as a standard procedure. The thickness of the layer of paste ranged from about 1/16 in to 1/2 in, depending upon the thickness of the explosive layer and the area of the block to which it was applied. The thickness was also varied from place to place on the block depending upon the vulnerability of a particular region. For example, on the bottom surface, close to the end remotest from the point of initiation of explosive, a region where reflecting waves are particularly destructive, the paste of white lead was applied quite thickly.

Although we did not make extensive metallurgical studies of the explosively attacked block, we did make a number of hardness traverses. The results were disappointing, particularly in the 4160 heat treated blocks, heat treated to a hardness of about 85 Rockwell B5 T. Here it appeared that the effect of the explosive was to anneal, or soften, the surface layer rather than harden it. This softening was slight amounting to 1 or 2 points Rockwell B5 T. We have not been able to establish definitively the cause for this softening but have conjectured that the heat imparted to the metal block by the explosive heats the surface, thereby annealing it. Compatible with this conjecture is the fact that explosives increase the surface hardness of annealed mild steel plates. It is also well known that the annealing temperature of a steel is a function of its carbon content, decreasing from 900°C for a 0.1 percent carbon steel to about 800°C for a 0.6 percent carbon steel. Theoretically, it is to be expected that under the conditions of explosive attack, the steel near the surface of the block will reach a temperature somewhere in this range although the temperature has never been measured experimentally. Further confirmation of this annealing action is the fact that we found the softening could be prevented by interposing a layer of asbestos paper between the explosive and the metal surface. When this was done, however, the shock of the explosive was degraded so much as to be ineffective.

The experiments have now been concluded because it does not appear that explosive will be very useful in bringing about surface hardening. The blocks used in this series of tests were sent to Rockwell-Standard where Mr. Komarnitsky has studied them carefully and will report to you his results.