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Structural and Modal Analysis Of Adapter Plates For Hydraulic Hammers And Skid Steers Under Real Work Condition

Análisis estructural y modal de las placas adaptación para martillos hidráulicos y minicargadores en condiciones reales de operación

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Abstract

In Perú the need for utility projects such as gas network installation for residents has increased the demand for the use of Hydraulic Hammers (HH) with mini-loaders, due to the low investment required compared to other machinery equipment and to the versatility. The easiness to interchange hydraulic hammers with buckets to complete the demolition and cleaning stages offers for contractors a higher productivity than manual operations. For that reason, the virtual design software Inventor Professional was used to design a suitable adapter plate with adequate resistance and durability, which has a direct impact on the structure of the hydraulic hammer and the hydraulic arm of the skid steers. Simultaneously, a basic animation was developed to explain the effect of the operation style over the hydraulic hammers and the adapter plates. Finally, for this development, it was considered the construction of an adapter plate as a fuse in the system, in case operators exceed the resistance capacity of the hydraulic hammer structure.

Keywords: Design, hydraulic hammer, skid steer, adapter plate, Inventor Professional, Ansys

Resumen

En Perú, la necesidad de proyectos de servicios como la instalación de redes de gas para los residentes, ha incrementado la demanda del uso de martillos hidráulicos (HH) con cargadores compactos debido a la baja inversión en comparación con otros equipos de maquinaria y la versatilidad. La facilidad para intercambiar martillos hidráulicos con cucharones para completar las etapas de demolición y limpieza ofrecen para los contratistas una alta productividad en comparación con una operación manual. Por esa razón, el software de diseño virtual Inventor Professional fue usado para diseñar una placa de adaptación con la resistencia y durabilidad adecuadas, lo cual tiene un impacto directo sobre la estructura del martillo hidráulico y el brazo hidráulico del cargador compacto. Simultáneamente, se desarrolló una animación básica para explicar el efecto del estilo de operación sobre los martillos hidráulicos y las placas de adaptación. Finalmente, para este desarrollo, se consideró la construcción de la placa de adaptación como un fusible en el sistema, en caso de que los operadores excedan la capacidad de resistencia de la estructura del martillo hidráulico.

Palabras clave: diseño, martillo hidraulico, minicargadores, platos adaptadores, Inventor Profesional, Ansys

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1. Introduction

In South America, it is common to build roads without service nets installed because the executed facility projects are limited by investment capital. The necessity to improve the quality of life and to expand services for residents opened a huge market for demolition products such as hydraulic hammers [1].

Projects such as gas pipe installations require building trenches, beginning with the cutting of hard surface concrete pavement or asphalt to create, on average, 20 cm wide openings. For demolition, hydraulic hammers mounted on a compact skid steer are used, which can also be utilized to clean the removed waste material and for restoration [2].

In Peru, for natural gas massification construction projects, a Case Skid Steer model SR220 and Hydraulic Hammer SB202 were used. The hammer has special features such as a solid body structure, a grease refilling valve located on the top of the body, and the narrowest box section width of 17 cm, which reduces the energy invested over kilometers of gas pipe installation [3].

At the same time, the demand for new operators and contractors to install gas pipes boosted the demand for systems of skid steer- adapter plate- hydraulic hammer. Due to dealer´s market strategies, the focus on the importance of the adapter plate and their potential impact on the performance and useful time of hydraulic hammers were lost. The demand for training, new strategies and different solving proposals increased when the rate of claims rose from 5% to 35%, particularly for irreparable damages in hydraulic hammers [4].

Independent research using advanced virtual analysis was made by the major local adapter plate manufacturer "Soluciones Barrera EIRL", which had a participation of 60% of products in the closed market of Atlas Copco SB202 and Case SR202. This company is one of the most innovative ones in the Peruvian market.

After evaluation of the nature of the failure and the recurrence, a relation was detected between poor operation skills, the extreme resistance and hardness of the adapter plate, and the presence of other manufacturers of adapter plates without adhering to engineering standards. Similarly, the focus was not on the evaluation and the control of damaging effects [5].

As a result, an objective was set to build the adapter plate as a fuse in the system. Static and dynamic virtual simulation were used to design a new adapter plate with Inventor Professional. Afterward, Ansys analysis confirmed the behavior. Complimentary with the registration of performance and claim records, a group of adapter plates was made to improve the building process, product quality, and finally cost reduction.

2. Materials and Methods

2.1. General overview

In 2004 the Camisea Gas project, which cost 3.9 billion dollars (USD), began a gas massification process in Peru. Due to the intensiveness of this activity, a method was set to install pipelines in the soil in a depth of 30 cm, This depth created the technical recommendation to build trenches with a depth of 70 cm. Some work was in streets paved with concrete or asphalt and for that reason, it was necessary to demolish the hard road surfaces that were previously cut in widths of 20 cm [6, 7] (Fig 1).

Figure 1. Trench building, demolition and excavation [8]

Historical reference sales from 2014 for a group of 15 new skid steer, adapter plate, and hydraulic hammer systems showed a high number of warranty claims resulting from failures on the solid body of the hydraulic hammers. After a thorough evaluation using a penetrant liquid, the formation of cracks on hydraulic hammers was detected.

An investigation was performed to understand the failure origin, which was related to the overload on the hammer. A possible explanation was extrapolated due to other failures in moil points, bushings, and pistons. At the same time, 4 skid steers showed initial microcrack formation in their arms. Consequently, a hypothesis was established considering the system of skid steer - adapter plate - hydraulic hammer as a single unit where vibration and resonance generated during the demolition process traveled through the system and produced cracks in the least tough part of the system. As a second part of the method, a new prototype considering the adapter plate as a fuse was established and is explained in this research [9].

2.2. Skid-steers a multipurpose machine

Skid-steers are used in different industries as multipurpose compact carriers for construction, handling materials vehicles, and agriculture equipment [10]. In combination with hydraulic hammers, some methods of demolition can be made, using as a recommendation the specification of hydraulic flow rate, static pressure, and the hammer weight resistance detailed as a reference [11].

Additionally, the decision of the size of the bucket was in relation to the density of material handled, in this case, old concrete or asphalt 5-20 cm thick and compacted soil was lifted from the surface into trucks as waste material. In this experience, the model SR220 from Case was mounted with 240 kg heavy-duty buckets with a capacity of 0.44 m3 reported by customers and supported by the brochure [12].

2.3. Selection of hydraulic hammer for operation condition

Boundary conditions were the minimum width of the trench, the depth of 70 cm and, as operations were inside the trench, the hammer lubricator nipple located by its design on the top of the hammer. A hammer with higher resistance for overload and built with minimum internal parts were used under endurance conditions. For that reason a Case Skid Steer model SR220, equivalent to Caterpillar model 236B was selected with a hydraulic breaker Atlas Copco SB202 with a solid body [13] (Fig. 2).

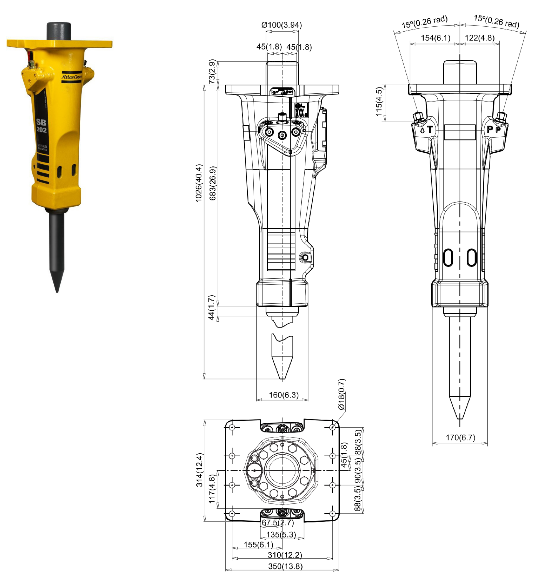

Figure 2. Hydraulic Hammer SB202 Atlas Copco [3]

2.4. Impact on the skid steer and hydraulic breaker durability

Good maintenance and adequate design of the adapter plate for Hydraulic hammer allows to obtain the maximum result. Diagnostic tests were made to detect minor failures in order to fix them, which is an important part of a preventive maintenance program. Contractors reported an operative availability between 61% and 81% after a strategic plan was applied to improve it [14].

The standard configuration was the use of SB202 due to its special features its patent design, resistance for overloads and higher location of the lubrication valve. The reliability of the hammer was not measured but was reported by contractors as higher than other products that they used.

2.5. Real work conditions

Crack formation as a result of the use of the hydraulic hammer was reported by Li *et al.* (2019) [15] using Ansys Workbench which showed the behavior in the arm structure in an articulate system, when a hydraulic hammer is used. Fundamental parameters about the potential impact and crack formation were taken referentially from the registered real operations. The hypothesis was to test the adapter plate as a fuse to protect the hammer and skid steer integrity, considering the maximum overload condition when operators use excessive hydraulic pressure with the arms-hammer over the surface for demolition, and in a non-aligned 90° angle of operation (between the hammer and the surface). This can be considered the most extreme operation condition and, for that reason, a line of research was open to optimize the adapter plate (Fig. 3).

Figure 3. Skid Steer working with Hydraulic Hammer SB202 [16]

2.6. Fabrication of adapter plate

Physical measurements were taken from the hydraulic hammer Atlas Copco SB202 and the top mounting region of the arm, taking into consideration the tridimensional measurements to connect both machines and, afterwards a tridimensional drawing was developed using the software Inventor Professional and Ansys to analyze the static structural and dynamic behavior under maximum impact frequency of 1800 blows per minute (BPM). For the analysis, the adapter plate was made independent from the system of the skid steer arm and the hydraulic hammer. Boundary conditions such as gravity, the weight of 16,750 N applied to the adapter plate and hydraulic force in contact regions with the hammer and the skid steer arm were applied.

2.7. Criteria for adapter plate redesign

The redesign of the adapter plate was made considering a soft material in the first stage of analysis, and following the results of the first six months, those were redesigned using a reinforcement which increased the lifetime to over one year of standard operation. The system skid steer-adapter plate-hammer was used for the demolition of road hard cover (old asphalt, concrete) and to break the compacted soil structure (Table 1).

Table 1. Boundary operational conditions for the system Skid steer-adapter plate – hydraulic hammer

Boundary conditions (Used for Inventor and Ansys simulation)	
Operation	Demolition
Machine weight Skid steer Case model SR220	33752 N
Coupling system	Mechanical
Material use for adapter plate	Carbon Steel ASTM A-36
A shift in a common Labor Day	12 h
Effective percussion time per shift	1-3 h
Total time used by month	30-90 h

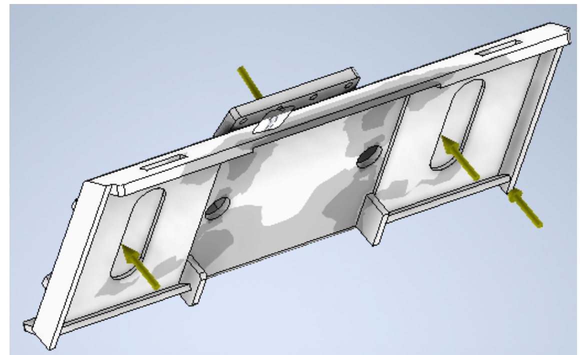

Figure 4. Adapter Plate built in Inventor

For the meshing analysis in Autodesk Inventor 2020 (Fig. 5), the average size element used was 0.05, the minimum size element 0.1, the grading factor 1.5 and the maximum turn angle 30 deg. Geometrically the adapter plate was designed considering flat shapes reducing the presence of curvatures. Referential recommendations are detailed in Table 2.

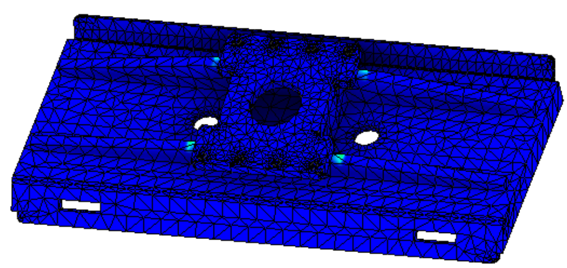

Figure 5. Adapter Plate Meshing

Table 2. Boundary operational conditions for the system Skid steer-adapter plate – hydraulic hammer

Parameters	
Element Average Size	0.1 - 0.05
Element Minimum Size	0.1 - 0.2
Grading Factor	1.5 - 3.0
Maximum Turn Angle degrees	30 - 60

3. Results and discussion

3.1. Static Analysis

Loaded static analysis was performed using Autodesk 2020 Inventor Professional, considering the weight of Skid Steer with attachments of 33,752 N (Table 1); as a result of the operation observed a weight of 16,750N was considered (Fig. 2). Due to the two contact regions between the arm and the adapter plate, a force of 8,375 N was applied to each contact area and a force of 16,750 N was applied to the contact surface between the adapter plate and the hydraulic hammer. (Fig. 4).

For the static analysis, the tensile yield stress of carbon steel ASTM A36 (Table 3) used is 250 MPa., with Young's modulus = 199.959 GPa, and Poisson ratio = 0.3. (Fig. 6). Assuming a maximum Von Mises Stress of 31.33 MPa (Fig. 6) and a deflection limitation of 0.25 mm, a maximum result of displacement of 0.09856 mm (Fig. 7) was obtained.

Table 3. Carbon Steel ASTM A36 Properties [17]

Material		
Name	Steel ASTM 36	
	Mass Density	7.85 g/cm3
General	Compressive Yield Strengh	250 Mpa
	Yield Strength	152 Mpa
	Ultimate Tensile Strength	400 Mpa
	Young´s Modulus	19.959 Gpa
Stress	Poisson´s Ratio	0.3 ul
	Shear Modulus	76.9073 Gpa

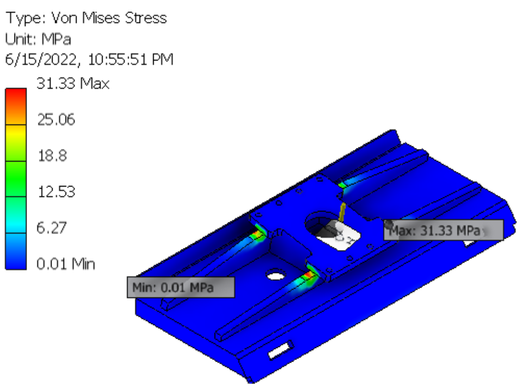

Figure 6. Von Mises Stress Static Analysis in Inventor

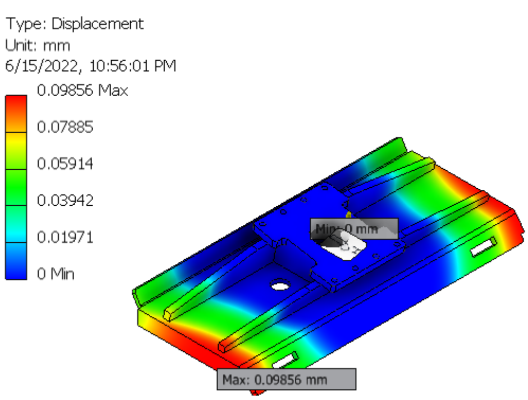

Figure 7. Displacement Static Analysis in Inventor

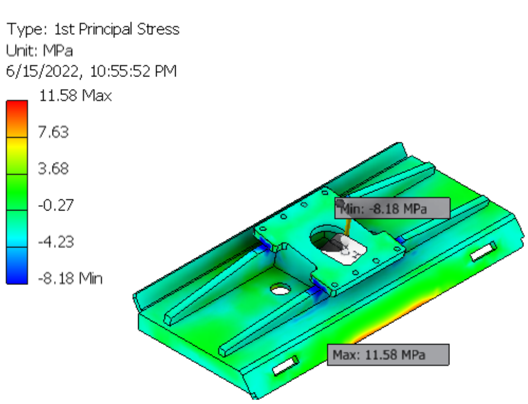

Figure 8. Maximum Tensile Stress Static Analysis

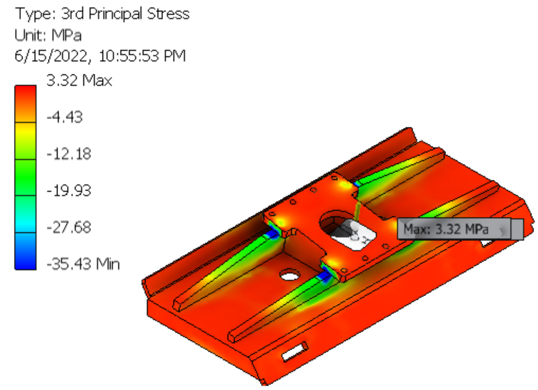

Figure 9. Maximum Compressive Stress Static Analysis

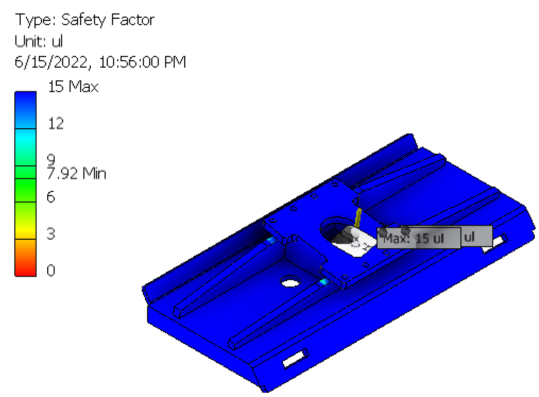

Figure 10. Safety factor Static Analysis

The maximum tensile stress of 11.58 MPa (Fig.8) is below the Von-Mises condition (32.38 MPa) (Fig. 7), because the stress was distributed throughout the whole structure. The maximum compressive stress was 3.32 MPa (Fig. 9), which was observed in the support structure interfaces between the hammer base plate and the skid-steer base plate. The maximum compressive stress of ASTM A36 carbon steel used is 152 MPa [18]. The minimum safety factor was 7.92 (Fig. 7) which means that we achieve a high factor of safety with this design [19] Table 4.

Table 4. Comparison Static and Dynamic Analysis

Type	Static Stress (Mpa)	Dynamic Excluding Prestress (Mpa)	Dynamic Including Prestress (Mpa)	Percentage Difference
Max. Principle Stress	11.58	12.37	23.95	48.34%
Min. Principle Stress	3.32	4.55	7.87	42.19%

3.2. Modal Analysis

The impact frequency of using one SB202 was in a range of 850-1800 blows/min (max 30 Hz). The total maximum deformation was 3.0405×10^{-6} mm in the contact region between the adapter plate and hammer and in the central region of the adapter plate areas with 0.098 mm (Fig. 7).

A stress drop for harmonic analysis was performed in Ansys Modal and Harmonic Response. As a first analysis, it is usual to evaluate where the stress relaxations and prestress removal took place in the adapter plate. Static stress was 11.58 MPa (Table 4) in the initial stage. As dynamic action starts, this situation gets relaxed first. Dynamic stress analysis was used to compensate for the static compression and to bring down the static effect to zero in order to reverse the resistance developed inside the material.

The Dynamic stress excluding prestress was 12.37 MPa (Fig. 11) and the total dynamic stress was 23.95 MPa (Table 4). Maximum principal stress and minimum principal stress percentage difference values of the static and dynamic results are 48.34% and 42.19% which is less than 50% (Fig. 12).

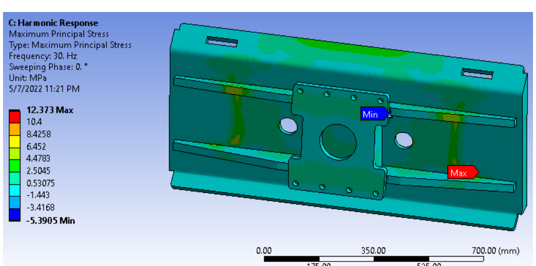

Figure 11. Harmonic Analysis in Ansys Max Frequency of 30Hz

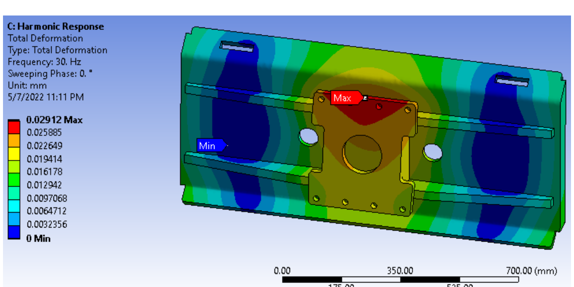

Figure 12. Maximum Principal Stress in Harmonic Analysis

3.3. Fatigue Analysis

Table 5 shows the resulting fatigue life analysis reported by Ansys, we had 1.00×10^8 cycles up to structural failure (Fig. 13). For that reason, using the hydraulic hammer and its operational performance of 600 and 1800 BPM and correlating with the operational hours per day, which results in a range of 308.64 to 925.93 days of operation before failure.

Table 5. Fatigue analysis per operation cycles

Item	Value	Units	Value	Units
Cycles before fatigue (one blow= one cycle)	1.00E+08		1.00E+08	
Hammers Blows Per Minute	1800	BPM	600	BPM
Considering one hour	60	min	60	min
Operational effective hours per day	3	hours	3	hours
Number of days	**308.64**	**days**	**925.93**	**days**

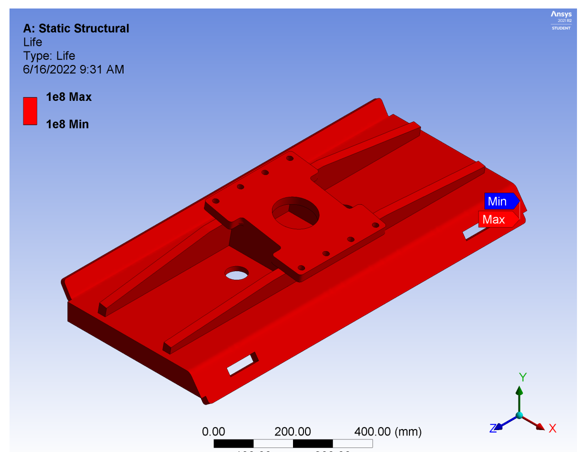

Figure 13. Fatigue Life Analysis in cycles

Similarly, the safety factor resulting from the fatigue analysis reported a minimum number of 4.3599 (Fig. 14) which is over 1 and we can consider this a reliable design.

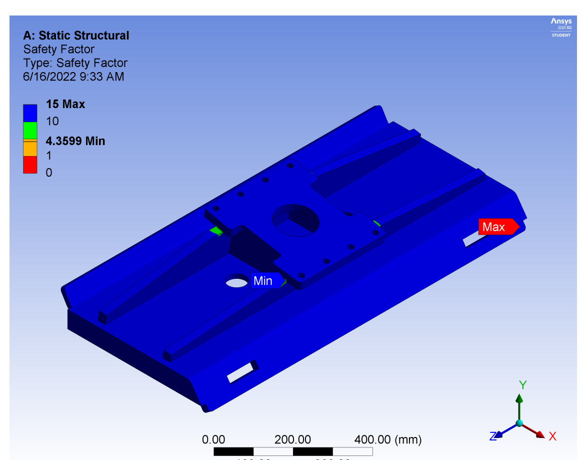

Figure 14. Fatigue Analysis – Safety factor

Due to the maximum stress of 31.33 Mpa (Fig. 6) with a safety factor of 7.92 (Fig. 10), this sustains up to 1.00×10^8 cycles (Fig. 13) before structural failure.

This performance supports the goal of this design attaining the maximum durability while also acting as a fuse protecting the hammer and skid steer structure if an overload happens. With the stress load reported it is still under the endurance limit, because despite the 1.00×10^8 cycles before fatigue, the safety factor is over 1 which means we have space for future optimization.

3.4. Building and welding process

The adapter plate was built using carbon steel ASTM-A36, with welding 6011 and 7018 with 5/32" size and for the final product an electrostatic paint RAL9005 was used, and each final product was registered with a progressive registration number for the product quality control and warranty management (Fig. 15).

3.5. Standard product for the market

As a marketing strategy, the supplier offered six months as a standard warranty and included a constantly updated optimization for final users with high reliability using new adapter plates as a backup in case of quality problems with the presence of cracks in the structure (Table 2).

Table 6. Record of adapter plates and qualitative performance

Plate	Fabrication	Time use (month)	Warranty (month)	Observation
1	15-Jan-15	6	12	Normal Wear
2	15-Jan-15	4	12	Normal Wear
3	15-Jan-15	8	12	Normal Wear
4	15-Jan-15	7	12	Normal Wear
5	15-Jan-15	12	12	Normal Wear
6	15-Jan-15	16	12	Small cracks
7	15-Jan-15	6	12	Normal Wear
8	15-Jan-15	8	12	Normal Wear
9	15-Jan-15	12	12	Normal Wear
10	15-Jan-15	14	12	Small cracks

After 14 months of use, a group of 10 adapter plates built simultaneously were physically evaluated along with their warranty claims. The results confirmed normal wear during operation and the presence of cracks after the warranty period of 12 months. (Table 6) At the same time, no cracks were observed in the solid structure of hammers or skid steer boom structure, and complementary animation and training videos were developed to explain the effect of inappropriate operation to customers [16]. Proper training and operation contributed to reducing damage to hydraulic hammers.

Finally, this product has been a probed solution from 2015 up to current date for skid-steers-hammers system for demolition application in Peruvian market; however, its price represents 20% of acquisition price, for that reason, it is recommendable to start an optimization research to reduce production costs. This adapter plate was standardized to be used by the majority of brands which work with Atlas Copco hammers and the serial production surpasses 500 units up to date with reliable performance and having, as a result, lower warranty claims and side effects over hydraulic hammers.

Figure 15. Adapter plate as final product

4. Conclusions

Stress applied during the demolition of hard road covers, pavement and asphalt, across the system including skid steer-adapter plate-hydraulic hammer was identified as the main concern of this study and the style of operation. For that reason, as part of an optimized product development, training videos were developed to improve operational skills.

Complementary to that, a warranty claim strategy was established to reestablish confidence in the products and an exclusive supplier was appointed including a reliable warranty response, which contributed to reintroducing the product reducing the warranty claims of failures in hydraulic hammers to a 99% during the following 12 months.

There is space for the optimization process because the safety factor obtained is higher than 7.95 and the difference percentage between static and dynamic results are lower than 50%, and in the industry, a reference of 20% is used to obtain the maximum resistance. However, the peaks of stress do not exceed the maximum tensile yield stress of ASTM A36 carbon steel which was 250 MPa, and the maximum compressive stress of ASTM A36 carbon steel was 152 MPa. The strategy confirmed the use of the adapter plate as an element to protect the hammer and skid-steer from deformation.

The adapter plate was demonstrated to act as a fuse protecting the hammer and skid steer arm, confirming our hypothesis. Continual innovation is recommended to improve the adaptor reliability and performance on job sites which will increase the product's reputation in the marketplace.

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